AGITATING, STIRRING
AND
KNEADING MACHINERY

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By HARTLAND SEYMOUR
Consulting Chemical Engineer

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PREFACE

I HAVE divided the whole problem of mixing into three classes: (1) The mixing of two liquids. (2) The mixing of two solids. (3) The mixing of a solid and a liquid. The first I have termed agitation or stirring, the second mixing, and the third kneading. In this volume only the first and third processes are dealt with, *i.e.*, agitating or stirring together two liquids and kneading a liquid and a solid. For information on mixing machinery, readers are referred to another volume in this series confined to that subject alone. I am aware that some of the machines I have described may be used to accomplish more than one of the above processes, but they have been dealt with here only so far as they are employed either for agitation or kneading. The machinery for accomplishing these processes only has been described, theory being omitted, in the belief that this method of treatment will be of more service to the practical chemical engineer than a discussion of the theory underlying the various problems of incorporating liquids and solids. This opportunity is taken to thank all those who have been good enough to assist me in the task of describing and illustrating the different types of machinery.

January 1925.

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CHAPTER I

INTRODUCTION

THE processes of mixing may be divided into three operations. The first is the mixing of two liquids, the second is the mixing of two solids, and the third is the mixing of a liquid and a solid. Though the term "mixing" may be applied to all three processes, for the purpose of this book I have dealt only with the first and the third, since I hold the first operation, *i.e.*, mixing two liquids, to be agitating or stirring, and the third, the mixing of a liquid and a solid, to be kneading, while the second operation, the incorporation of two solids, I define as mixing, and therefore outside the scope of this work.

Under the two headings of "agitating" and "kneading" are collected mixtures and blends of substances between very wide extremes, from the thinnest of liquids to the toughest solids, so that it is impossible to divide the problem of agitating or kneading into certain well-defined classes, since in some cases it is necessary to incorporate several substances of widely varying viscosities or degrees of toughness, at the same time subjecting them either to a heating or a cooling influence. In these circumstances it becomes impossible to say that

such and such an agitator or kneader will give good results with some materials but is of no use for others. All that can be done is to enumerate some of the substances on which the various units are being used and to suggest that they will give good service on similar mixtures.

Machinery for agitating and kneading does not lend itself easily to classification other than on the most elementary lines, but it may be said that such machinery employs one of three principles—the vessel itself rotates; the mixing element rotates and the vessel is stationary; both the vessel and the mixing element are in motion. Beyond this classification it is not feasible to go, because the variety of machines operating on one or other of the above principles is bewildering, and the number of mixing elements of varying styles is legion. Most of these are designed on certain basic principles of the theory of incorporating two liquids or a solid and a liquid, but this book is concerned with the machinery alone, and the theories of mixing are of little use to the practical chemical engineer, so they are not dealt with. Again, most of the machines described have been evolved after considerable experiment on substances within certain physical limits and may reasonably be expected to give satisfactory results with any substances falling within such limits.

Even with such physical limits fairly well defined it is impossible to say that a certain machine will

not give good results outside those limits, and I have seen mixing machinery giving excellent service under conditions for which it was never designed—conditions which would confound all the theorists. It might here be remarked that our present knowledge of the theory of agitating and kneading problems is quite inadequate and is sadly in need of overhaul and extension.

When the chemical engineer is selecting an agitator or kneader for some specific process, what he is after is a machine which will produce the best mixture at the least cost. That means he wants a machine that will turn out a perfectly homogeneous mixture of whatever he proposes to put into it, a mixture free from lumps or streaks of improperly mixed fluid. This is his aim, and, of course, all other factors should be subordinated to this object. On the other hand, he will probably find at least half a dozen types that will meet this need, and his choice must again be narrowed. Given that the machine will perform all that is required of it, the chemical engineer should look next for simplicity of construction and general ruggedness, for, if he operates machinery, however efficient, that is always requiring adjustment, replacement, or repair, he is going to add very heavily to his process costs. Other factors to be examined are the power consumed and the time taken per unit of output. Of two machines which will turn out the same quality and quantity of product in a given time

one may consume nearly twice as much power as the other.

Other points to be looked for are the convenience of charging and discharging the vessel in the light of the facilities available for these operations at the works, the space occupied, the type of motive power required and how it is best applied, the tightness of the container and the jacketing equipment, and the provisions made in the design to prevent the entry of dirt and grease or oil from the driving mechanism. All these factors are of importance and should be considered in order of merit, depending upon the specific mixing problem to be handled and the operating conditions obtaining in the works.

As far as the actual agitating or kneading elements are concerned, the chemical engineer about to make a selection will find himself confronted by an endless variety, each of which has its protagonists and antagonists. In this book it has been impossible to describe or illustrate all the multitudinous types of mixing elements, but I believe the foremost types have not been overlooked, though there are, of course, many variations of such types which have not been considered at all, though they are just as efficient as those selected for treatment.

The chief types of stirring apparatus for agitating two liquids or for kneading very light mixtures may be divided into paddles fixed horizontally on

a vertical axis, propellers rotating at the end of a vertical shaft near the bottom of the container, turbine agitators, helical screw agitators, and ribbon agitators. Each of these types has been treated in some detail with particulars of its capacity and field of application. Air-lift agitation, which owes its development largely to the metallurgical industries, has also been dealt with, as I believe it has a great field of usefulness to the chemical engineer, especially where continuity of process is aimed at.

For the efficient agitation of light liquids there is little to choose between the various forms of paddle agitators, propellers, helical screws, ribbon agitators, and turbines. So far as my observation has gone, these types are equally efficient, and the final selection of complete agitating equipment will be chiefly governed by the other factors, *i.e.*, the type of vessel, method of charging, discharging and operating.

In the case of a light liquid being incorporated with a solid or a heavy liquid, a form of agitator which breaks up the heavier body and disperses it through the lighter is essential. Some of the helical screw and ribbon agitators do this very well, but many of the ordinary paddle agitators merely swirl the entire mass round the vessel and there is really no mix at all.

Kneading machines for incorporating heavy plastic masses are either vertical or horizontal, *i.e.*,

the kneading element operates either on a vertical or a horizontal axis. In the type of kneader usually installed for dealing with plastic masses, the vessel takes the form of two half-cylinders joined down the centre, the central ridge dividing the vessel in two, serving to cut up the mass into two parts, which are kneaded backwards and forwards by a pair of longitudinally fixed blades rotating in opposite directions. The effect in such a machine is to work the mass to and fro from one kneading element to the other.

Here again there is an endless variety of kneading elements, designed to meet the requirements of every conceivable kneading process. Some consist of knife-blades or simply bent shafts fixed at either end of the trough, while for pill masses and similar substances a kneading element of the shape of a helical screw conveyer working in a horizontal trough is used. It has been impossible to describe every kneading element in use, but attention, I believe, has been paid to the chief types.

CHAPTER II

AGITATING AND STIRRING MACHINERY

The term "agitation" is here used as meaning the movement imparted to a suspension of finely divided solids in a liquid, or as movement designed to mix thoroughly two or more liquids. The main objects of agitation may be summed up as:

1. To provide an opportunity for the most efficient dissolution or leaching of one or more constituents of a finely divided material. An example of this is the dissolving of gold or silver from ore by a cyanide solution, or copper from a cuprous ore by weak sulphuric acid.
2. To furnish means of washing insoluble materials suspended in a solution, to purify the former or recover the latter; for example, any stirring in a decantation operation.
3. To ensure a continuous supply of a mixture uniform in composition and percentage, where the original feed may vary; *e.g.*, in cement slurry equalising tanks.
4. To mix liquids or liquids and solids to secure uniform and regulatable conditions for precipitation; *e.g.*, the causticising reaction between milk of lime and soda ash to make caustic soda.

This chapter will deal only with the agitation of such mixtures which act as a more or less free-flowing liquid, and not with heavy, viscous mixtures which must be beaten and kneaded.

The measure of the value of an agitator is not its first cost, but the cost of obtaining the best economic results. This is determined by the cost of agitation per ton per hour and by the time required to obtain the desired results. In general, the free movement of all particles of solids in the liquid, or a constant change in the relative positions of the solids and the liquid, is the first essential for maximum dissolution or reaction in the shortest time, rather than the rapidity of circulation. There may, in fact, be rapid circulation without efficient dissolution. Though most agitating problems can be handled with one of the standard types of agitator, it has from time to time become necessary to make changes in these standard designs to suit particular conditions, until the variety of agitators now available has become almost bewildering. In general, however, agitators may be divided into six broad classifications :

1. The paddle type.
2. The propeller type.
3. The helical type.
4. The spiral type.
5. The turbine type.
6. The air lift type.

The simplest of these is the paddle agitator, which, as its name signifies, consists of a number of paddles fixed to a central spindle which is revolved, the action of the paddles thus agitating

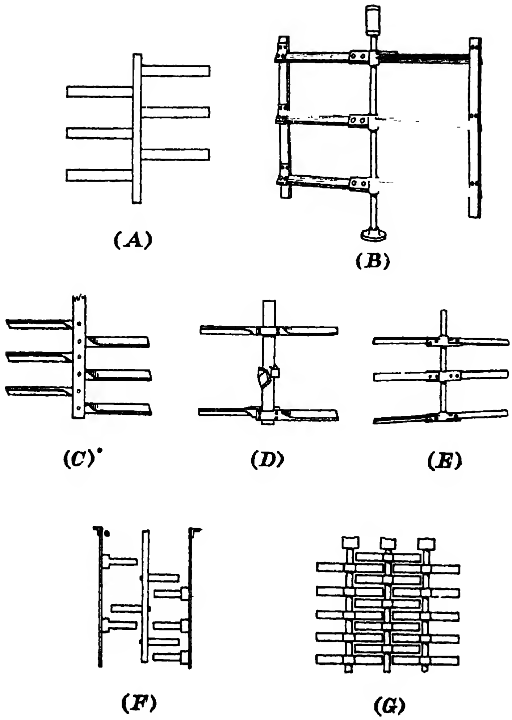


FIG. 1.—PADDLE AGITATORS.

the liquids, which may be mixed with various degrees of efficiency according to the type and the design of the agitating element. The paddle stirrer has, for some reason or other, fallen into disrepute, but it is surprisingly efficient in mixing mobile liquids, a quality revealed by some recent tests carried out by Dr. W. L. Badger, of Ann Arbor (see *Chemical and Metallurgical Engineering*, Vol. 27, p. 1176, and Vol. 28, p. 1077). In these tests water and a saturated sodium chloride solution were mixed in a 5 ft. by 5 ft. tank of 600-gallon capacity by means of a two-blade, 3 in. by 3 in. paddle, shaved to a 45 deg. angle. The conclusions arrived at by these tests were that:

1. The plain paddle stirrer is much more efficient than is commonly supposed.
2. The 600-gallon tank was completely stirred in less than one minute at any speed above 22 r.p.m.
3. The appearance of the liquid is no measure of the stirring efficiency.
4. At speeds above that of the minimum time of stirring there is a rapid rise in power consumption.

At the same time, the simple paddle type of stirrer is not the most efficient means of mixing liquids, because it tends to impart motion to the entire mass at the expense of relative movement of the constituents which are to be mixed. This

action produces a swirling motion, and to get over this difficulty several modifications of the simple paddle have been put into practice with good results. The paddles have been shaved to an angle so that a vertical as well as a horizontal movement is imparted to the liquids. In other cases, vertical blades have been fixed to the revolving paddle with others fastened to the structure of the vessel, this being known as the gate paddle stirrer. Other modifications include helical vanes constructed in the walls of the vessel so as to force the liquid upwards in an inclined direction, baffles attached to the sides of the vessels and staggered with the paddles, and paddles located at the foci of ellipsoidal vessels.

Fig. 1A shows the paddle agitator with unshaved blades in its simplest form equipped with six blades attached to a central spindle in a circular tank. A rotary movement is imparted to this spindle by various forms of drive which will be discussed later under its appropriate heading.

Fig. 1B is a later modification of the paddle stirrer known as the gate type. This consists of six metal blades fastened at an angle to a central spindle, the ends of the blades being connected as shown by two vertical members. The movement of these blades is horizontal, so that a swirl is produced; but combined with this simple horizontal swirl is the upward inclined movement brought about by the fact that the blades are set at an angle,

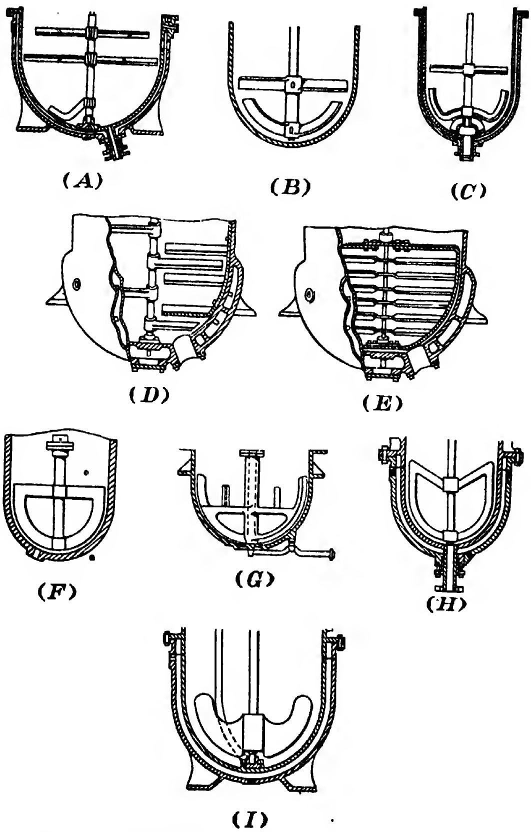


FIG. 2.—VARIOUS TYPES OF PADDLE AGITATORS.

while the two outer vertical members ensure that any tendency to "stagnate" by the liquid is obviated. Considered all round, this type is very efficient and will suffice very well for ordinary chemical agitation at a low power cost.

Figs. 1C–1G illustrate some of the modifications of the simple paddle stirrer. Fig. 1C is a simple wood agitator with shaved blades and is a form commonly used for small tanks; 1D is an agitator provided with six blades, shaved, the central pair being placed at right angles to the outer two. These blades are adjustable for height. A vertical metal shaft provided with horizontal metal blades is shown in 1E; 1F is equipped with plain blades, three in number, on the spindle, staggered with five located irregularly on the sides of the vessel. A paddle stirring equipment for a larger vessel is shown in 1G, where two outer spindles carry eight blades each, and a central spindle is provided with ten blades, These spindles may be driven at the same or differential speeds, according to the arrangements of the drive.

So far we have been concerned only with the simplest form of paddle stirrer for mixing liquids in cylindrical vessels. In many operations, however, ellipsoidal, circular-bottomed, and other shaped vessels are employed, and in these cases modifications of the ordinary paddle stirrer are introduced to suit the shape of the vessel and also to over-

come the difficulties of agitation produced by vessels which have a curved bottom.

Fig. 2 illustrates some of the variations made in the ordinary paddle stirrer to overcome these difficulties. In Fig. 2A is shown a simple shaved blade paddle agitator adapted for stirring in a circular-bottomed vessel. If an ordinary agitator with horizontal blades were used in a vessel of this shape the result would be a " stagnant " spot at the bottom of the tank; the introduction of the smaller bent paddle arm at the foot of the spindle obviates this, and ensures that the liquids at this point are kept moving and sent upwards where they come under the effect of the more vigorous action of the horizontal stirrers. This is probably the simplest type of agitator for service in vessels with circular bottoms.

Another simple type is that in Fig. 2B, where a curved pair of stirring arms is located at the end of the spindle, and set, looking down from the top of the spindle, at an angle to the horizontal shaved blades. A more complicated type is shown in Fig. 2C, where two pairs of curved arms send the liquid upwards. Fig. 2D is a type of agitator where arms fixed to the sides of the vessel are staggered with those on the spindle. Shaved blades with an outside sweep similar to that in Fig. 1B are illustrated in Fig. 2E. The type of agitator in Fig. 2F I have found to be particularly efficient in agitating the more viscous liquids at low

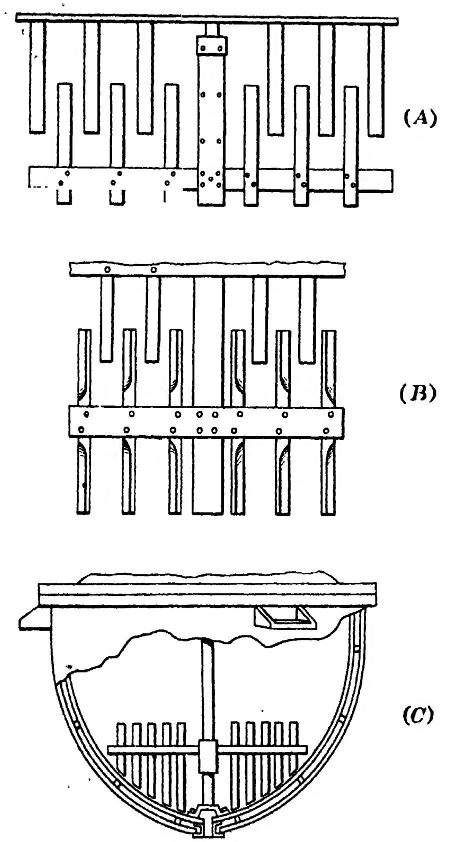


FIG. 3.—GATE TYPE AGITATORS.

power cost. This consists of a simple D-shaped member carried on a central spindle; the face of the member may be perfectly plain, or both the straight and the curve may be shaved. Three other modifications, typical of present-day practice are shown in Figs. 2G, 2H and 2I.

The gate-type stirrer, introduced to obviate the disadvantage of the swirl produced by plain, unshaved paddles, has met with considerable success, and, in its various forms, is widely in use. The gate stirrer for agitation in cylindrical vessels is shown in Fig. 3A. In this form a number of plain arms is attached vertically to a rotating paddle, and staggered with a number of members attached to the top of the cylinder. In Fig. 3B is a similar arrangement, but in this case the blades are bevelled, and a better mixing action is obtained than when the plain blades are used. Fig. 3C illustrates the arrangement of blades when the vessel has a curved bottom.

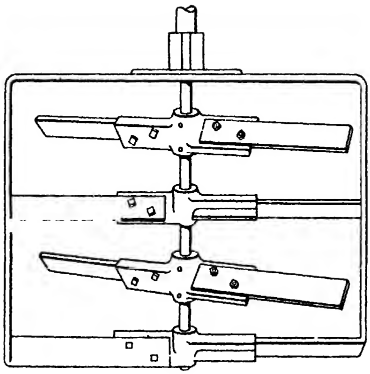
In the duplex or two-motion stirring element the pairs of blades, which are shaved, are reversed alternately on the spindle so, that the liquid is forced upwards in different directions. This type is shown in Fig. 4A for a cylindrical vessel, and in Fig. 4B for a circular-bottomed tank.

This agitator consists of two sets of paddles in which the outside sweep and the paddles attached to it are driven by means of a hollow shaft or sleeve. The centre paddles attached to the central vertical

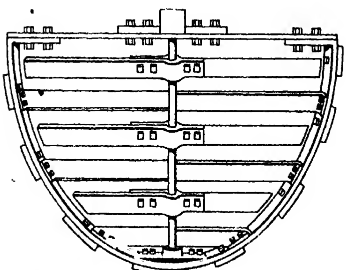
shaft, which passes through the hollow shaft, are driven by a small gear; being inverted and half the size of the large gear, these paddles revolve in the opposite direction at twice the speed. In the case of the stirrer shown in Fig. 4A adjustable steel scrapers, alternately arranged, are attached to the outside sweep and scrape the jacketed surface of the kettle at each revolution of the agitator, thus preventing the contents from sticking or burning. The sweep on this agitator turns at 10 to 15 r.p.m., and the inner paddles run at 20 to 30 r.p.m.; the ratio of the large gear and pinion is 2 : 1, and that of the smaller, 1 : 1.

For mixing heavier liquids a similar type of double-motion paddle agitator is used, except that the vertical shaft extends down through the bottom of the sweep and rests in a step bearing. A machine of this type is used in the manufacture of chocolate, graphite, heavy oils, soap, and polishes.

In cases where it is desirable to remove the agitating equipment from the vessel, the stirrer and its accessories are mounted on a bracket which can be raised by means of a handwheel. Three standard agitators of this type are shown in Fig. 5. The stirrer, Fig. 5A, consists of a series of cast-iron paddles which are set at an angle, thus giving the material being agitated an upward motion. The bottom paddle conforms to the shape of the kettle, its purpose being to prevent materials from settling about the bottom of the shaft. All these paddles



(*A*)



(*B*)

FIG. 4.—DOUBLE-MOTION STIRRERS.

are adjustable up or down. This agitator is well adapted to the mixing of light substances where only simple stirring is required, such as mixing oils

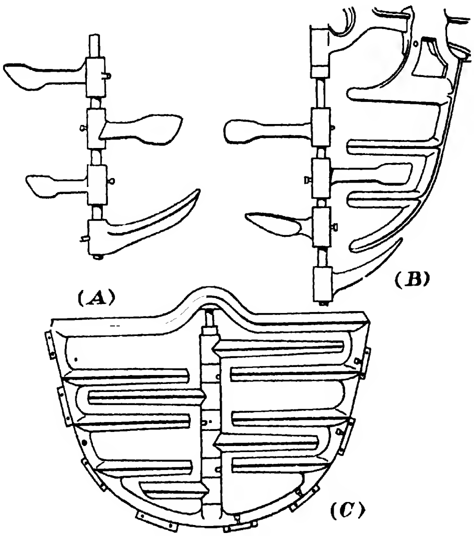


FIG. 5.—ADJUSTABLE PADDLE AGITATORS.

and colours; it is also useful in assisting evaporation. The speed of this machine is from 20 to 30 r.p.m., and the gear ratio 1 : 1. The stirrer shown in Fig. 5B is similar to the one described with the addition of a set of stationary paddles or arms to prevent the material being mixed from revolving

round the kettle in a body. This agitator is mainly used for heavy oils, printing inks, oil soaps, and for kneading casein compounds, sizings, and rubber cements. The speed of this machine is 20 to 30 r.p.m., depending upon the product, and the gear ratio is 1 : 1. The double-motion agitator is also constructed on this principle, as shown in Fig. 5c.

The paddle stirrer is obviously very simple and requires very little explanation. Provided an agitating element is employed which keeps the entire contents of the vessel in motion, and obviates all "dead spots," good results may be obtained by the use of the various types described here.

While on the subject of paddle mixers, it might be as well to mention a system recently introduced which effects considerable saving in mixing equipment. This takes the form of a simple paddle stirring element which, together with its drive, is bolted to some convenient spot on the wall of the shop. Mixing takes place in a cylindrical vessel run on casters. The liquids to be mixed are poured into the vessel, which is pushed to the agitator, the shaft of which is lowered into the tank for stirring. On completion the agitating element is raised and the tank pushed off to its appropriate department, when the stirrer is ready for the next tank. Such an arrangement is exceedingly simple and means that mixing can be carried out on one machine instead of several.

In its simplest form the propeller agitator consists of a two- or three-bladed propeller which revolves at the end of a shaft near the bottom of the vessel, forcing the liquid upwards with a

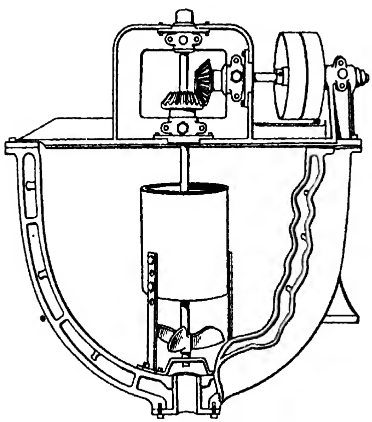


FIG. 6.—PROPELLER AGITATOR.

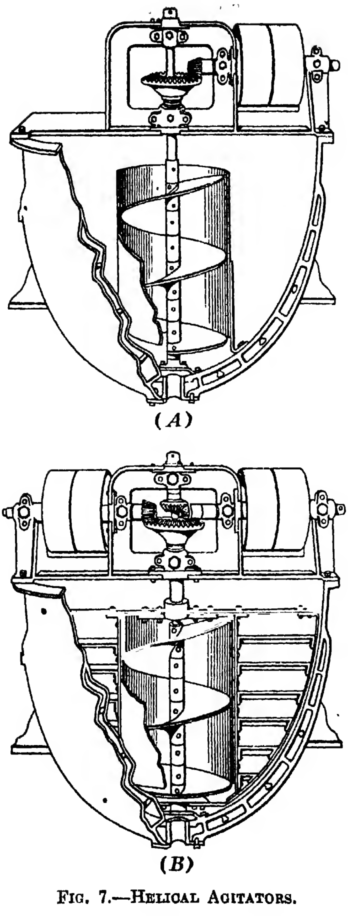
swirling motion. A propeller screw agitator is shown in Fig. 6, where the mixture is forced up through the drum, the swirl being broken by means of stationary vanes. The clearance between the bottom of the kettle and the drum is adjustable. This machine has a speed of 15 to 200 r.p.m., the

gear ratio being 1 : 1. Standard types of two- and three-bladed propellers are also shown in Fig. 6.

For the treatment of such materials as chloride of lime, chromate of potassium for dye works, sugar of lead in the production of chrome colours, etc., an egg-shaped container is used carrying a centrifugal propeller driven by fast and loose pulleys through bevel gears placed above or below. To break the currents baffle bars are set across the top of the container. This machine has proved remarkably efficient for dissolving china clay, blanc fixe, and chloride of lime without the application of steam; for instance, a machine with a capacity of 1100 gallons will dissolve 14 tons of china clay in 24 hours with the expenditure of only 3 h.p.

Propeller agitators are also made in portable forms for dealing with from 1 to 1000 gallons of light or heavy fluids. In this machine the propeller is direct-connected to a motor, which can be clamped on the side of any vessel, the current for the motor being obtained through a length of flex. The propeller and its shaft are made of monel metal plated either with silver or bronze-nickel.

The helical screw agitator consists of a series of cast-iron blades or wings so fitted together as to form a screw which is surrounded by a steel drum or tube so that the assembly constitutes a form of spiral conveyor. The rapidly revolving screw conveys the mixture from the bottom of the vessel up through and over the drum, constantly changing



(A)

(B)

FIG. 7.—HELICAL AGITATORS.

the material in contact with the inner surface of the vessel, and producing a very thorough and rapid agitation. A bridge type agitator of this class is shown in Fig. 7A, a form popular in the chemical industry, and also among textile manufacturers for mixing such substances as size and starches. In this machine the conveyor screw normally operates at 100 to 125 r.p.m., depending upon the consistency of the product being handled. Such an agitator is constructed to deal with from 10 up to as much as 1000 gallons in one mix; the gear ratio for the 10-gallon machine is 10 : 1, and that for the 1000-gallon machine is 5 : 1.

A similar form of agitator is mounted on a bracket for lowering into a vessel, and is used for mixing soaps, pastes, toilet creams, and ointments.

In the type of agitator illustrated in Fig. 7B the helical screw with its conveyor tube is combined with a paddle agitator. In this machine a very thorough agitation is effected as two radically different motions are obtained. The central conveyor screw drags the material up through and over the drum as in Fig. 7A, while the outside sweep with paddles attached works through the mass to be mixed in the opposite direction, forcing it downward, where it is again caught up by the screw. Adjustable steel scrapers, alternately arranged, are attached to the outside sweep, scraping the inner surface of the vessel at each revolution.

This agitator is designed for mixing heavy semi-

fluid or pasty substances; also for mixing a heavy material with a lighter one, as the screw is designed to draw the heavy material constantly away from the bottom. This agitator has been used with great success in the manufacture of products such as heavy soap specialities, clay, and silicate binder for paste-board, heavy chemicals and similar substances. The outside sweep operates at 10 to 15 r.p.m., while the central screw turns at 100 to 125 r.p.m.

A special form of helical screw mixer is the "Triplex" shown in Fig. 8. In this machine the mixing mechanism consists of vertical spiral flights in triangular position. Each flight consists of right- and left-hand spirals, the left-hand spirals being above the centre of the vessel, and the right-hand spirals below. In operation, each spiral flight rotates and all spiral flights revolve as a unit. The left-hand spirals lower the light material, and the right-hand spirals raise the heavy substance, while the rotating spiral flights and side bars set up an agitation encompassing the entire contents of the container. In this way the mix is three-way, up, down and around.

The main drive shaft and the flight shafts, which are vertical, are mounted on ball thrust bearings, and held in alignment by bearings carried on the spider at the bottom of the container. All gearing is enclosed and lubricated. The spiral flights are castings mounted on heavy steel shafting.

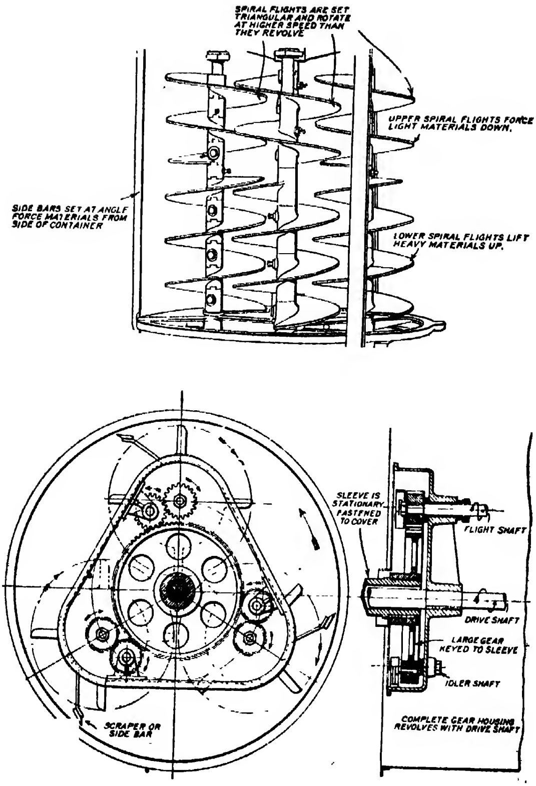


FIG. 8.—TRIPLEX HELICAL AGITATOR.

The containers for these agitators are made of boiler plate, and may be jacketed for heating and made air-tight for discharging the contents with air pressure. The drive on these machines is either belt or direct motor.

These agitators have been introduced to deal

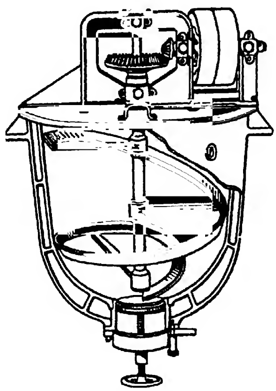


FIG. 9.—SPIRAL AGITATOR.

with a wide variety of products, such as varnish, glue, pastes, inks, paper sizing, oils and greases, dyes, colours, rubber cement, soaps, enamels, and celluloid compounds.

A standard form of spiral ribbon agitator is shown in Fig. 9. This consists of a wrought-iron ribbon, attached to a central shaft, which starts at the bottom of the container and follows the contour

of the vessel to whatever height is desired. In operation, the ribbon raises the material at the sides of the vessel and carries it toward the centre. This machine is used for mixing the lighter pastes. The central shaft turns at 15 to 20 r.p.m., employing a gear ratio on the smaller machines (10 to 50 gallons) of 2 : 1, and 5 : 1 on the larger machines (500 to 1000 gallons).

Three other types of ribbon agitators are shown in Fig. 10. That in Fig. 10A is adapted for end discharge; the materials fed into the container immediately come into contact with the double spiral agitator, where they are revolved and agitated, the outer spiral carrying the mixture to the discharge end.

The centre discharge agitator is shown in Fig. 10B. This has been designed specially for materials which have a tendency to pack, and will deal effectively with the most obstinate materials in about 15 minutes, depending upon the speed of the agitator. The shaft upon which the blades are mounted is made of cold rolled steel.

The cut-out agitator is shown in Fig. 10C, and is built for central discharge. This machine is fitted with double or triple strength spirals, depending upon the consistency of the substances undergoing mixture. It has a leather strip attached to the outer spiral so as to enable the agitator to scrape closely to the bottom. Every alternate section of the outer spiral of this agitator is omitted, thereby

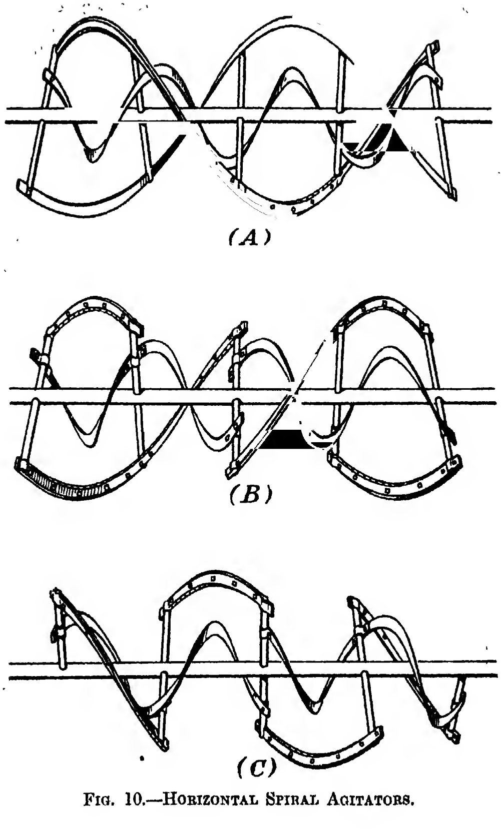


FIG. 10.—HORIZONTAL SPIRAL AGITATORS.

making it easier for the agitator to pass through heavier materials.

A tank spiral agitator is shown in Fig. 11. In this machine the agitator is made of wrought iron and is galvanised. The outer spirals, made of flat bar iron, cause an upward movement of the

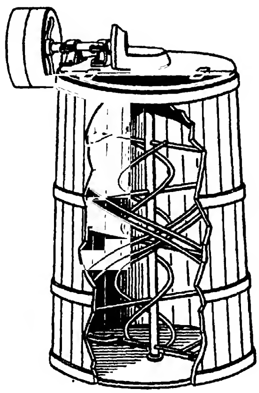


FIG. 11.—SPIRAL AGITATOR.

materials, which are carried down again by the inner spirals. The tank is made of 1½–2 in. ash or oak and bound with heavy iron hoops, and is usually cylindrical in shape.

Such a type of mixer is used for syrups, paints, shoe dressings, and similar materials. In some works it is employed in batteries of from two to twelve machines, equipped with gearing and clutches

for operating the machines independently or all together. The 50-gallon machine has a speed of 80 r.p.m., while the largest, *i.e.*, 500 gallons, has a speed of 60 r.p.m.

The turbine agitator is actually a development of the paddle stirrer, in which the blades are so formed that the force exerted on the fluid is mainly centrifugal. One type of turbine agitator is shown in Fig. 12, consisting of a rotor-mixer and baffle boards, vertical extension shaft, mounting plank and ball-thrust agitator drive. In this machine the blades of the turbine are set at 45 deg., tending to draw the contents of the tank downwards at the centre, the centrifugal action throwing the liquid out toward the sides, so that the resultant current is vertical from the centre of the tank, sweeping the bottom and going up the sides of the tank to impinge and turn over against the baffle board at the top. The baffle boards, guided by the baffle staves, serve to break up the simple swirling motion of the liquid and thrust it directly into and through opposing currents generated by the rotary motion of the whole mass. In the turbine agitator it is usual to employ high speeds.

The turbine agitator shown in the figure is made with rotors from 8 in. to 40 in. in diameter, these rotors being made of cast iron, hardwood, brass, cast bronze, hard lead, monel metal and aluminium. All-metal and all-wood turbines for these agitators are also shown in Fig. 12.

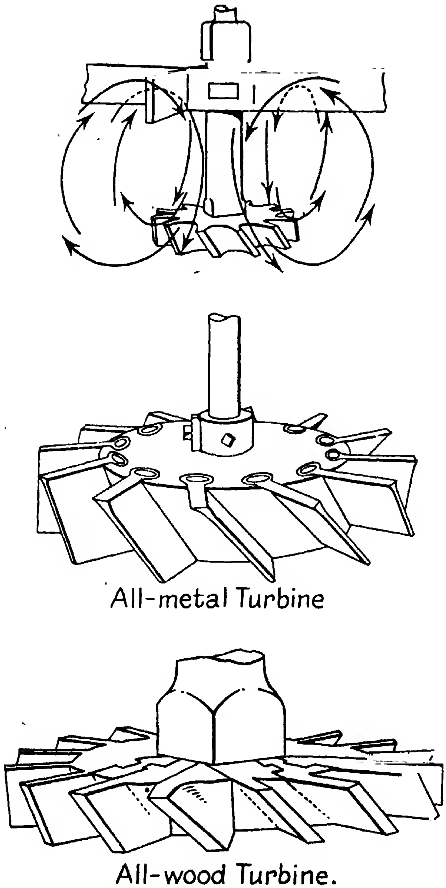


Fig. 12.—Turbine Agitator.

Fig. 13 shows a crutcher agitator which consists of a series of cast-iron propeller blades fitted together so as to form a continuous screw, which

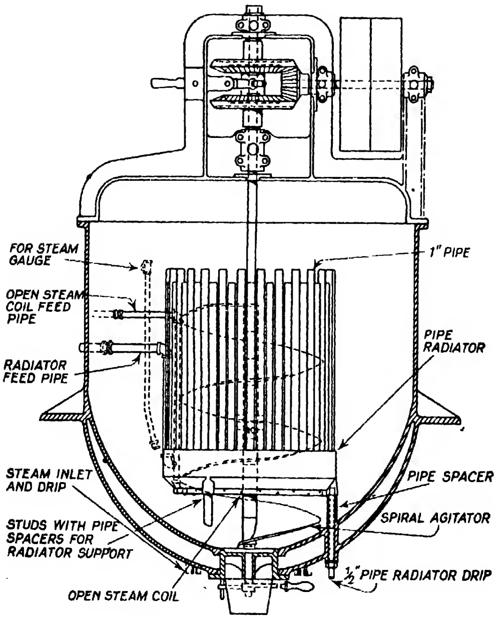


FIG. 13.—CRUTCHER.

revolves inside the radiator, thus forcing the material up, part of it going through and part over the pipes. As shown in the drawing, the bottom of this screw comes close to the bottom of

the kettle, so that material is drawn from this extreme point, there being no dead pocket. The constant motion of the screw shears up any lumps. By reversing the motion of the agitator, the screw drives the material down and thus assists in emptying the kettle quickly. An open steam coil placed directly below the radiator can be used either for admitting live steam to the contents or for cleaning out the kettle.

Crutchers of this type are constructed with a capacity from 1000 lb. to 5000 lb. The gear ratio on the 1000 lb., 1500 lb. and 1800 lb. sizes is 2 : 1, and on the 2600 lb., 3600 lb. and 4500 lb. sizes, $2\frac{1}{2}$: 1.

During recent years the air-lift type of agitator has been introduced, with considerable success, in the metallurgical industries, and its use is rapidly extending to chemical works. The greatest use for agitation in metallurgy has been in the cyanide process, where large tonnages of ore, ground to pass 30 mesh as the maximum, are agitated to dissolve as much as possible of the gold or silver. The reduced ore has a specific gravity varying between 2·5 and 3·5, and is suspended in from one to three parts of liquid. In this field the first essential for maximum dissolution is the free movement of all the solid particles in the pulp—that is to say, a constant change in the relative positions of the liquid and the solids, rather than rapidity of circulation pure and simple or a homogeneous movement of the whole pulp.

Originally, rotating paddle agitators were commonly used, and later air was added. The next step was agitation by circulation of the pulp in a high conical tank by means of an air lift in the centre. This type showed considerable improvement in the first essential of good agitation. In this, as in the other forms, it was found necessary to give a much more violent agitation than the chemical treatment of the material required in order to maintain the pulp in suspension.

At this point agitation was carried out in stages. When continuous agitation became an established practice, it was found that there was a strong tendency for the coarser materials in the pulp to collect on the sides of the tank. To meet this condition the agitator shown in Fig. 14 (Dorr) was designed.

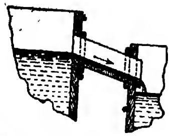
The Dorr agitator consists of a cylindrical flat-bottomed tank containing a mechanism which brings the pulp from the bottom zone of the tank to the centre, elevates it, and distributes it evenly over the surface. The operating mechanism comprises a central vertical shaft driven by bevel gears and revolving in bearings suitably supported from the tank. The bearings are above the pulp level and carry the weight of the revolving parts, so that no step bearing is needed. At the lower end of the shaft is a head casting to which is attached an air lift column or pipe, reaching almost to the bottom of the tank, and carrying,

hinged to its lower end, two arms with plough blades, which are adjustable in a vertical plane by means of chains. To the head casting are attached two distributing launders, with short lengths of chain suspended from their ends. Air for the operation of the air lift is brought in, either through a pipe through the bottom of the tank, provided with a ball check valve and shutter, or at the top through the vertical shaft, which in such cases is made hollow. This description will be better followed by reference to the diagram Fig. 14.

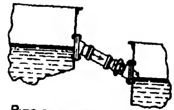
When the tank is filled with pulp and the central shaft is revolving, the plough blades on the arms sweep the bottom, moving the pulp to the centre. The pulp is raised by the air lift to the head casting and passes to the revolving launders, from where it is distributed evenly over the surface of the liquid in the tank. The swinging chains at the end of the launders prevent solids from adhering to the sides of the tank.

The object of making the arms adjustable as to angle is to avoid any difficulty in starting up after a shutdown. In such cases these arms are raised by means of the chains and a winch, the mechanism is started, and the arms are then gradually lowered to their normal position. To guard against damage in the event of the agitator being overloaded, the driving pulley is equipped with a hub and a break pin.

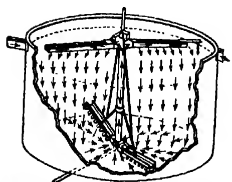
Where the agitator must be operated with a



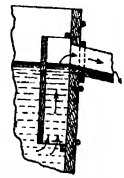
Wood launder between agitators



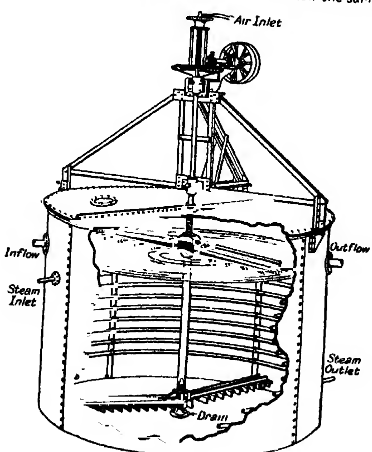
Pipe connection between agitators



Continuous agitation with Dorr agitator
Arrows show direction of pulp movement



Open box inside agitator to remove pulp from point below the surface



Reaction Type.

FIG. 14.—AIR LIFT AGITATOR.

variable pulp level, suitable discharge openings are provided in the air lift column, so that circulation is maintained. Openings are also provided in the side or bottom of the tank, depending upon whether the agitator is to be used for continuous or intermittent operation.

Four principal factors have an important bearing on agitator operation—specific gravity of the solids, the dilution of the pulp, the screen analysis of the solids, and the percentage of non-granular or clayey material. While it is not possible to assign definite values or limits to these factors, experience indicates that conditions may be considered as normal for agitation when the specific gravity of the solids is 2·8, specific gravity of the pulp 1·25, size of the solids – 60 mesh, and the amount of non-granular materials 30 per cent.

The speed at which the arms of the agitator should be operated is determined by the nature of the material being treated. Two to four r.p.m. is considered normal, though heavy or coarse material, or a very dilute pulp in which the solids are of a granular nature, will require a higher speed.

The power required for the mechanical operation of the Dorr agitator arms varies with the size of the tank and the character of the material handled. In all cases it is small, due to the low speed of operation and the relatively small amount of solids moved by the arms. At one plant, agitators

Table I.—Dorr Agitators.

Air and Power Measurements.

Clark Air Meter Used.

Size Agitators. Diam.	Size Agitators. Depth.	Screen Test. +100.	Screen Test. +200.	Dilution of Pulp.	Specific Gravity Dry Ore.	Specific Gravity Pulp.	Height Lift, Inches.	Diam. Lift, Pipe.	R.P.M. Rakes.	Alt. of Mill.	Air Press Lb.	Cu. Ft. Free Air–Min. Min.* (1).	Cu. Ft. Free Air–Min. Norm.† (2).	Cu. Ft. Free Air–Min. Max.‡ (3).	Mch. H.P. Motor Input.
20′	12′	1·5	18·8	1·5 : 1	2·7	1·27	5	5	2·5	7,500	10·5	6·1	11·1	32·3	
											12·0	6·1	7·1	—	—
15′ 6″	16′	14·0	43·0	2 : 1	2·63	1·26	6	5	2·75	6,200	12·0	3·2	6·5	11·5	0·054
18′	16′	14·0	40·0	1·5 : 1	2·65	1·33	10	7	2·0	6,200	15·0	—	14·4	—	0·22
18′	16′	35·8	64·8	3 : 1	2·65	1·18	10	7	5·0	6,200	25·0	—	32·8	—	0·22
12′	16′	1·2	12·5	4·7 : 1	2·73	1·12	9	5	3·5	4,400	15·0	—	5·8	13·7	—
20′	19′ 6″	8·8	15·2	1·7 : 1	2·72	1·33	7	6	3·2	11,400	20·0	13·4	18·4	31·4	—
20′	19′ 6″	8·8	15·2	1·7 : 1	2·72	1·33	11	6	3·2	11,400	20·0	19·7	33·6	44·3	—
20′	19′ 6″	8·8	15·2	1·7 : 1	2·72	1·33	15	6	3·2	11,400	20·0	32·2	38·2	—	—
17′	10′	—	17·0	2 : 1	2·7	1·26	—	6	7·5	9,000	12·5	4·3	9·1	10·4	1·09
32′ 8″	11′	—	17·0	2 : 1	2·7	1·26	—	8	4·0	9,000	12·5	25·3	29·0	30·0	2·80
24′	12′	—	6·5	1·3 : 1	2·65	1·38	6	7	4·0	7,200	16·0	13·8	16·6	36·8	1·25
23′ 6″	11′ 6″	—	6·5	1·3 : 1	2·65	1·38	—	7	4·0	7,200	18·0	14·3	16·6	35·8	—
30′	14′	16·6	44·6	2·3 : 1	2·5	1·22	5	12	3·5	5,700	25·0	—	6·3	—	1·0
28′	20′	7·3	20·2	1·5 : 1	2·7	1·33	13	9	3·0	5,000	13·5	—	15·0	—	—
30′	10′	0·5	6·5	2·6 : 1	2·7	1·20	—	8	2·7	6,000	17·5	17·6	19·7	27·3	–
36′	20′	18·0	43·5	1·6 : 1	2·56	1·30	19	9	—	5,000	16·5	—	25·0	—	–
21′ 5″	18′	2·3	24·8	2 : 1	2·56	1·26	—	7	3·25	7,500	13·5	5·5	10·5	16·3	–
40′	25′	20·9	49·6	1·2 : 1	2·7	1·50	10	10	2·75	9,500	20·0	42·0	55·0	65·0	–

* Minimum air to keep pulp moving. Pulp not flowing to end of distributing launders.
† Normal agitation. Amount of air required in general practice.
‡ Maximum air could reasonably use. Strong and violent agitation.

16 ft. diameter by 16 ft. deep, handling a pulp 57 per cent. – 200 mesh with a specific gravity of 1·26, require ½ h.p. each. At another plant, agitators 30 ft. diameter by 14 ft. deep, agitating a pulp 65 per cent. – 200 mesh with a specific gravity of 1·22 use 1 h.p. per agitator.

The air required is low—on an average pulp of reasonably thick consistency in which the solids are not coarser than 80 mesh, 15 cu. ft. to 20 cu. ft. of air per minute at 15 lb. to 20 lb. pressure is usually ample. Coarse granular material and substances of high specific gravity require more air than fine, light material in a pulp of the same consistency. The table on p. 62 gives representative air and power requirements for various installations of Dorr agitators.

In continuous agitation three agitators are usually arranged in series, for each agitating unit. A difference in level of from 4 in. to 15 in. between the first and second, and between the second and third tanks affords a gravity flow from one tank to the next, the tanks being as close together as possible.

The feed of the first agitator is introduced over or through the side of the tank at a point a few inches above the pulp level. The discharge from each agitator is taken off as an overflow, and is the feed of the next lower one in the series. The points of feed and discharge are usually diametrically opposite one another. The loss in mill head,

from feed to final discharge, varies from 18 in. to 30 in.

Open launders of steel or wood usually carry the pulp from tank to tank, though pipe connections, if preferred, may be fitted. The bottom of the connecting pipe or launder is about 12 in. below the top of the discharging tank, and enters the receiving agitator a few inches above the level of the pulp. This level, in turn, is governed by the elevation of overflow or discharge of that tank. In this way any number of tanks may be arranged in series. If, for any reason, it is desired to remove the pulp at any level other than at the pulp surface, an open box may be connected to the overflow and the pulp thus removed from any desired depth in the tank. Such an arrangement is to be preferred in the case of a coarse pulp or one in which segregation may take place.

The process for the manufacture of phosphoric acid from phosphate rock and sulphuric acid presents a practical application of continuous reaction. There is fed to the first of a series of three reaction agitators 100 lb. of phosphate rock and 100 lb. of 60 deg. Beaumé sulphuric acid per minute, together with the proper amount of return solution from the washing system. At a point about 18 in. from the top of the tank an overflow pipe is attached through which the mixture resulting in this first tank gravitates to the second; the mixture from the second flows to the third

in the series. Hence, the resulting mixture, consisting of strong phosphoric acid and calcium sulphate mud, leaves the last tank in the series continuously at a given rate regulated by the rate of feed to the first reaction tank.

The size of tank necessary for a given quantity of the mixture to pass through such a system is determined by the time required for the reaction and the rate of feed calculated volumetrically. If it is desired to feed at the rate of 10 cu. ft. per minute, and the time of agitation required for the completion of the chemical reaction is two hours, the total agitating capacity required will be 2 ft. by 60 ft. by 10 ft. Dividing this capacity among three tanks, each should contain 400 cu. ft., that is, tanks 10 ft. in diameter by 5 ft. 3 in. deep below the overflow. Adding 18 in. to prevent boiling over, splashing, etc., gives a total depth for each tank of 6 ft. 9 in.

Typical applications of this system of continuous agitation are found in the manufacture of caustic soda from soda ash and lime, phosphoric acid from phosphate rock and sulphuric acid, and aluminium sulphate from bauxite and sulphuric acid. Borax from colemanite, barium carbonate from barium sulphide and soda ash, and the extraction of iron stains from barytes are other suggestive applications.

Two typical flow sheets and data are given below, one for bleaching finely-ground barytes

and the other for the manufacture of phosphoric acid from phosphate rock and sulphuric acid. On account of the confidential nature of most chemical operations it is impossible to publish very much data regarding the results being obtained. In studying these flow sheets it must be remembered that local conditions have a material influence over all chemical operations.

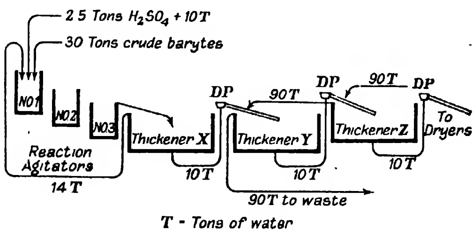


FIG. 15.—BARYTES BLEACHING.

BARYTES BLEACHING

Fig. 15 shows a flow sheet showing a proposed continuous process of bleaching finely-ground crude barytes.

Flow Sheet Data :

(1) 30 tons crude barytes bleached per 24 hours in 20 per cent. H_2SO_4 solution.

(2) Barytes discharged from all thickeners at one part water to three parts barytes by weight.

(3) 2·5 tons H_2SO_4 lost for each 30 tons of barytes bleached.

(4) Washed barytes to be practically free from acid.

(5) Barytes fed to agitator all -- 300 mesh.

Calculations :

Let Y and Z equal pounds H_2SO_4 per "T" in the respective thickeners. Equating total pounds *out of* and *into* each thickener, we have :

$100Y = 90Z + 5000$ lb. (10 "T" at 500 lb. per "T")

$100Z = 10Y$

$Z = 0{\cdot}1Y = 5{\cdot}5$ lb. H_2SO_4 per "T"

$Y = 55$ lb. H_2SO_4 per "T."

Conclusions :

Since 10 "T" at 5·5 lb. H_2SO_4 per "T" pass out of Thickener Z with the washed barytes, the 30 tons when dried will contain 55 lb. H_2SO_4 or 1·83 lb. per ton of barytes. This amount may be lowered by using another thickener or more wash water.

Phosphoric Acid

Fig. 16 is a typical flow sheet for the continuous production of phosphoric acid from phosphate rock and sulphuric acid.

Flow Sheet Data :

(1) 75 tons phosphate rock (35·3 per cent. P_2O_5) treated per 24 hours, with 68 tons 60 deg.

Bé. H_2SO_4 and 195 tons of 17 deg. Bé. liquor (10 per cent. P_2O_5).

(2) Producing 50,160 lb. P_2O_5 (95 per cent. extraction) and 100 tons insoluble solids (sp. gr. 2·32).

(3) Discharge from all thickeners = 1·8 to 1 solution to solids by volume.

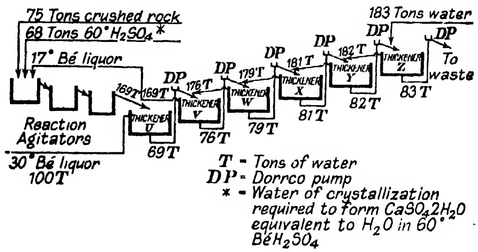


FIG. 16.—PHOSPHORIC ACID PRODUCTION.

(4) Total soluble solids = 1·54x per cent. P_2O_5 in solution.

(5) To produce phosphoric acid solution containing 22 per cent. P_2O_5 (30 deg. Bé.).

Calculations :

Let U, V, W, X, Y, and Z equal pounds of dissolved P_2O_5 per "T" in respective thickeners.

Equating pounds *out of* and *into* each thickener :

$$169U = 169V + 50{,}160 \text{ lb.}$$
$$245V = 176W + 69U$$
$$255W = 179X + 76V$$

$$260X = 181Y + 79W$$
$$263Y = 182Z + 81X$$
$$265Z = 82Y$$

$U =$	498·0 lb.	P_2O_5 per "T"
$V =$	201·2 lb.	" " "
$W =$	84·8 lb.	" " "
$X =$	35·4 lb.	" " "
$Y =$	13·8 lb.	" " "
$Z =$	4·3 lb.	" " "

Conclusions :

The 100 "T" going to storage at 498 lb. per "T" equals 49,803·6 lb. P_2O_5 recovered, or 99·2 per cent.

The standard construction of the Dorr agitator is iron and steel throughout, though wood tanks are employed under certain conditions; in some cases concrete tanks are used. Usually each agitator is a self-contained unit, all mechanism being supported on the tank. Where the building construction permits, the agitator mechanism may be carried on the roof trusses.

Where acid pulps or corrosive liquors have to be handled, special construction may be employed. Where the conditions are suitable for the use of wood, tanks of fir or redwood are built. The mechanism in contact with the pulp or liquor is of clear pine assembled with bolts and dowels of hickory, except that the plough blades are of maple, acid-proof iron or antimonial lead. Above

the pulp or liquor the construction is of iron or steel, though wood is sometimes used to support the mechanism.

An all-metal construction naturally gives longer life to the installation than wood. In this case steel tanks lead-lined or otherwise suitably protected are used. Lead-covered iron or steel, with bronze, gunmetal or antimonial lead in their proper places, are used for parts in contact with the liquor. All parts above the top of the tank are of standard metal construction.

The simplest form of agitator drive consists of a pair of gears, the power being derived from a belt pulley. In some cases the gears are totally enclosed to protect them from dust, dirt and fumes; the bearings are babbitted and lubricated by means of grease-cups. A design of this type will stand a good deal of ill-treatment, and is especially adapted for batch mixing where it may be necessary to change the drive from one machine to another. The drive can also be equipped with an electric motor, mounted as a self-contained unit, with positive drive through spur gears. The motor is usually $\frac{1}{4}$ h.p., 110 or 220 volts, and turns at 1740 r.p.m., the speed of the vertical shaft being reduced to 20 to 150 r.p.m.

A wide field for the successful application of ball and roller bearings is provided by the drives of agitating and kneading machinery, and Fig. 17A illustrates a typical example. It has been found

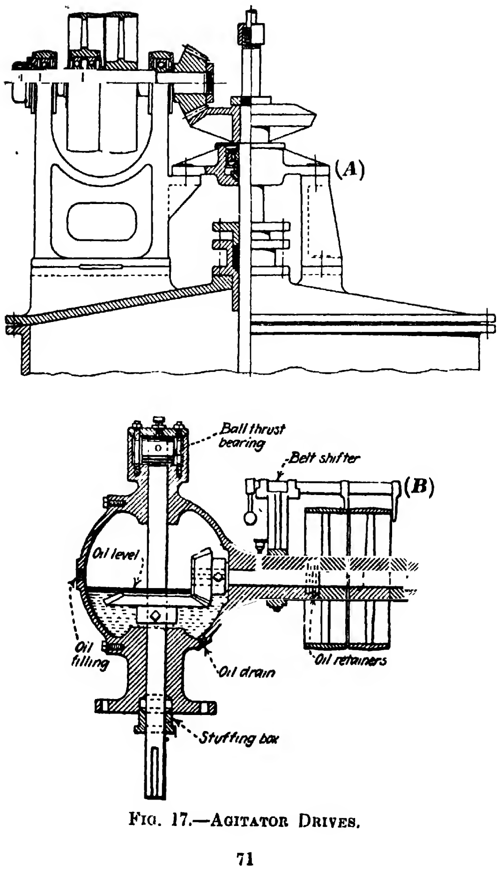


FIG. 17.—AGITATOR DRIVES.

best practice to suspend the agitator shaft, and, as the bottom of the shaft is guided in a plain bearing of some kind, which will wear slack, it is important that the ball or roller bearings be mounted in a spherical seating to accommodate the deflection of the shaft. Where necessary a gland can be mounted below the bearings as shown in the drawing.

In all applications of this nature it is important to consider carefully the effect of the process on the bearings, *i.e.*, whether the temperature will be excessive; if it will be possible to afford the bearings thorough protection against moisture, and if there are likely to be present strong acid fumes which would cause corrosion of the parts. In Fig. 17A the driving shaft is shown carried in a bracket bolted to the top of the container. The bevel pinion in this case is above the crown wheel, but this can obviously be reversed if desired. The drawing shows one agitator shaft; in the case of more than one shaft being employed the method of mounting would be the same in each case.

Where the agitator belongs to the two-motion type, the outside sweep is driven from one gear operating a hollow shaft, while the paddles are driven from another gear by a shaft passing through the hollow shaft.

In the direct-connected drives operated by motor, it is customary to cast the entire agitator frame and motor pan in one piece, which ensures a strong,

compact, durable unit that can be used under a variety of conditions where either continuous or intermittent agitation is necessary. Such a drive is designed for loads from ½ h.p. to 1½ h.p., the speed reduction being obtained by worm gears, with single, double or quadruple threads, giving reductions of 12½ : 1, 25 : 1 and 48 : 1. In some cases the entire drive with the stirring element and its motor is mounted on an overhead runway and is made to serve a line of containers in succession.

Where the duty is heavy it is usual to provide ball thrust bearings on both the horizontal and vertical shafts to carry the vertical load and the thrust of the pinion.

In the case of a battery of agitators, the power is derived from a single horizontal shaft, driven by pulley, and transmitted by gears to the vertical shaft of each unit.

The latest type of agitator drive is shown in Fig. 17B, which consists of a completely enclosed drive with the gears running in oil.

CHAPTER III

KNEADING AND MASTICATING MACHINERY

In the type of kneaders where the mixing is accomplished with the machine operating on a vertical axis, the mixing element usually takes the form of a series of vertical blades. In some cases these blades are straight, in others they are twisted, and there is an endless variety of designs and modifications of this type of machine.

A simple type of vertical kneader is that shown in Fig. 18A, which is used for mixing inks, tooth pastes, cold creams, shaving creams, pulps, and colours. This machine embodies three distinct movements, the blades covering every part of the tank. This unit is equipped with two sets of mixing blades, which not only revolve upon their own axes, but also around the tank at the same time. The blades are constructed of heavy tool steel and are driven by a pinion at the upper edge of the tank meshing with an annular gear under a guard. The mixer cross arms are prevented from working loose by taper pins and keys.

A similar unit is that shown in Fig. 18B, where the blades, instead of being straight, are twisted. As a general rule, where such machines are used, the vessel rotates as well as the mixing element, especially in the smaller sizes. The container is fitted on a bevelled gear wheel, and the mixing element, pivoted on the vertical member of the main frame, is swung into position, both the container and the

blades being operated together. The efficiency of this type of kneader is high, and a good mix can be obtained in a few minutes.

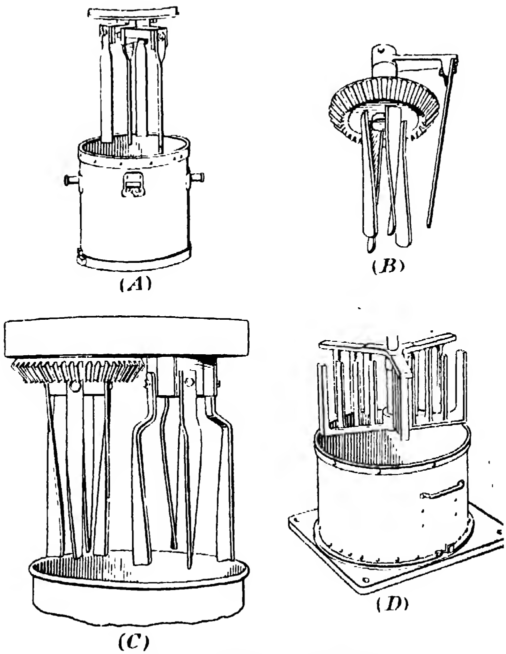


FIG. 18.—VERTICAL KNEADERS.

A larger machine of a similar type is shown in Fig. 18C, where the mixing is done by two sets of blades in the revolving pan. By means of the

lever the pan is thrown out of gear and remains stationary while the blades continue to revolve and knead the contents, which can then be drawn off during agitation. The blades in this machine are of heavy steel and are suited to continuous and arduous work. The flow space required by a unit of this type is 73 in. by 32 in.; the driving pulleys are 30 in. diameter by 5 in. wide, and should, for the best results, turn at 35 r.p.m.

Another type of vertical kneader is that in Fig. 18D, in which the masticating apparatus can be raised clear of the container, thus making it easy to remove the vessel and clean the moving parts. These elements are in two parts, the bottom part revolving while the top section is stationary. The moving knives follow the bottom of the pan closely, and the upright projections are interlaced by the dropping fingers carried on the stationary tripod which rests on and is held by the container.

A mixer commonly used for ointments and similar work is that shown in Fig. 19A, in which the kneaders are double-acting. The containers are mounted on wheels and are fitted with special plug valves for filling into tins when the stirrers are in motion or in store. The containers can be run under the kneaders and elevated by means of a small hydraulic ram actuated by a few strokes of the pump. When mixed, the tap is turned and the weight of the container empties the water from the

hydraulic cylinder into the cistern again and gradually sinks to the floor level.

For ointments, face and vanishing creams, soaps, boot polishes, emulsions, and other preparations where liquid pastes are blended and cooled in the process to prevent settling, the vertical kneader shown in Fig. 19B has proved to be very useful. In this unit the stirrer element is nickel plated, and an automatic scraper gear keeps the pan clear round the sides. The pan is enamelled and double jacketed for steam heating or water cooling during mixture.

Fig. 19C is a kneading machine recently introduced in Germany in which a pair of arms are moved in elliptical paths towards one another in a rotating pan. A clutch is provided in the pan driving gear which is thrown out of engagement on the mixture becoming stiff, when the pan rotates in the opposite direction owing to the movement of the mixture. The pan is rotated by a worm gear from a shaft, on which the clutch is fitted. This clutch comprises a member splined to the shaft and provided with inclined teeth engaging a mating member fixed to the shaft. On the resistance to rotation increasing owing to the stiffening of the mixture, the inclination of the teeth effects the disengagement of the clutch. Re-engagement is effected by means of a foot lever. The kneading arms are arranged on either side of the axis of the pan and pass one another in their orbits.

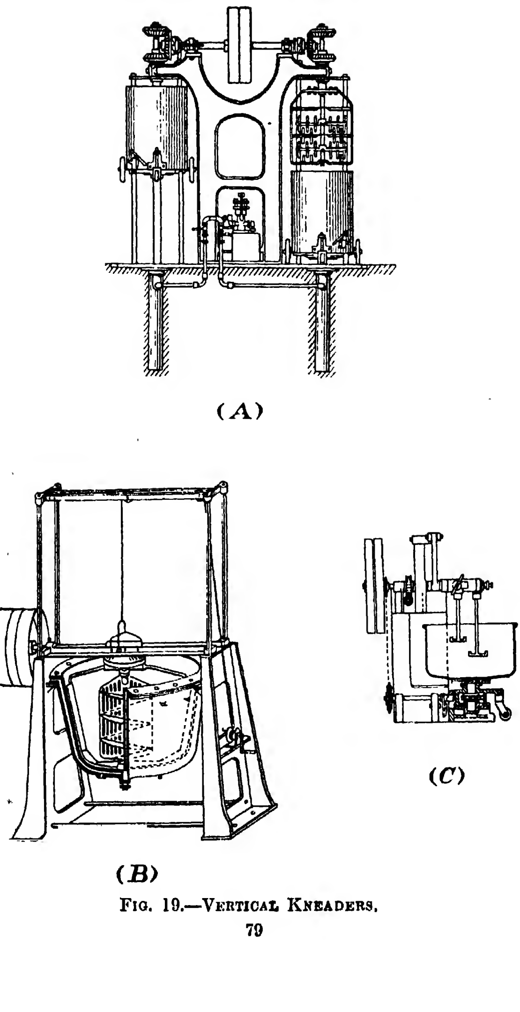


Fig. 19.—Vertical Kneaders.

They are mounted on cranks and are equipped with extensions connected by links to a fixed pin.

The horizontal kneading machine has proved to be one of the most practicable methods of blending and mixing pastes. Machines of this type usually consist of some modification of a horizontal trough, jacketed or otherwise, in which are rotated horizontal bladed or specially shaped shafts, shafts carrying spiral ribbons similar in design to those employed for agitating but working horizontally, or shafts carrying knives designed for the special purpose in view.

A typical machine for kneading all kinds of materials, and for mixing, incorporating, malaxating, or masticating is the "Universal," which is made in a variety of types, depending upon the nature of the material to be treated, one type of the "Universal" being shown in Fig. 20A. Machines of this class can be erected by any good mechanic with the aid of spanners and lifting tackle. Table II (p. 99) gives some idea of the various capacity of these kneaders. Among the materials being dealt with successfully are almond paste, asphalte, bone fat, cachou paste, carbon paste, casein, cellulose, chocolate, colours, crucible paste, drugs, enamel, creams, glues, gelatine, rubber, lacquers, linoleum, lithopone, chemical manures, clays, varnishes, paints, pill masses, pulps, superphosphate and yeast.

The fundamental principle underlying the many types of these machines remains the same: all of them consist essentially of a rectangular trough terminating in two hollow semi-cylinders disposed in a horizontal plane parallel to one another. In these semi-cylinders are blades or mixing arms of special form revolving at different speeds.

Theoretically the nature of the blade is determined by a plane which intersects each cylinder in such a manner that the surface of the cylinder coincides with the orbits described by the outline of the blade in its revolution. This plane, of elliptical outline, in one revolution intersects successively every point on the surface of its cylinder, so that no particle of material can escape coming under the action of the blades.

The action resulting from the movement set up is too complicated to be followed and described, but the effect is to produce in a short space of time a homogeneous mixing of all molecules contained in the trough.

The chief characteristics of kneading and mixing machines of such a type as the "Universal" may be summed up under the following two heads :—

1. The peculiar kneading blades (mixing and kneading arms) which are constructed in different shapes according to the nature of the material being dealt with.

2. The kneading blades are made to revolve either backwards or forwards, and can be instantly

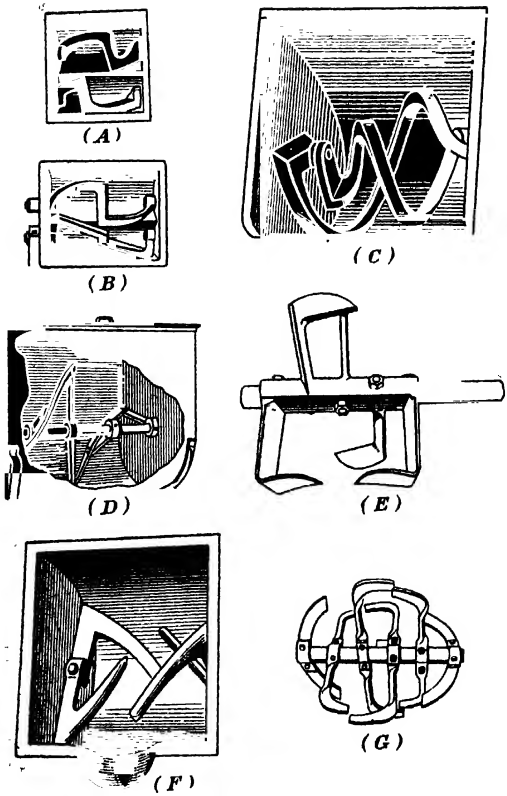


Fig. 20.—Horizontal Kneaders.

stopped by means of a reversing apparatus, whereby the process of mixing and kneading is accelerated, and the discharge of the material greatly facilitated.

The reversing apparatus consists of two loose pulleys, which revolve in opposite directions, between which is situated a disc, fixed on the shaft but free to move axially. The pulleys are easily and quickly brought into or out of contact with the disc by means of a hand wheel, so that either a forward or a backward movement is imparted to the blades. By simply holding the hand wheel the machine is thrown out of gear instantly. This apparatus therefore renders the machine self-contained, and dispenses entirely with striking gear usually required for belt-driven machinery.

The kneading troughs of the machines are mounted according to requirements. When the materials are to be filled into the machines without lifting apparatus, the troughs are placed as low as possible. When the materials are supplied from the floor above the machines, or by means of elevators, the troughs are fitted with outlets in the bottom and can be mounted so as to allow of trucks being run underneath.

By means of a simple hand winch, or, in the case of the larger machines, an automatic apparatus, the trough can be raised and tilted forward so that the kneaded mass can be thrown out on to a table, or into a truck of suitable height. The tilted posi-

tion of the trough naturally renders the cleaning of the machine easy and expeditious.

Either the trough or the blades, or both, may be made, as required by the materials to be treated, in cast or wrought iron, steel, bronze, or special metal; while in cases where the materials to be kneaded exercise undue wear upon the metal, a renewable lining is fitted to the trough, and the blades are specially protected.

A special feature of this type of machine is employed in such cases where the materials require heating to facilitate the process of mixing and incorporating, or where cooling of the mass under treatment is considered necessary or desirable. In either case the blades may be constructed hollow or the trough may be jacketed to permit of heating by steam or cooling by a circulation of cold water. The materials are so designed that all the usual operations of charging, working and emptying can be performed without the necessity of disconnecting the steam or water supply. These machines are also built to operate under vacuum.

The trough of one type of these machines is entirely of cast iron, and is divided through the blade bearings so that the blades can easily be removed and the interior surfaces thoroughly cleaned. This is very convenient where materials of varying colours or varying coarseness have to be treated. Such machines vary in capacity from ½ to 8 gallons, or 2 lb. to 56 lb., the capacity

being calculated for substances of specific gravity equal to glazier's putty.

For materials requiring water-tight troughs and blade journals such as light, greasy, semi-liquid or batter-like masses the troughs are composed of sheet-iron wrapper and two cast-iron ends firmly bolted together. The wrappers are always ground on the inside, but the casting skin is left on the end castings. A machine of this type has a capacity of from 4 to 22 gallons.

Masticators with heatable trough and blades have proved of immense value in the preparation of such masses as gutta percha, bitumen, balata, rubber, insulating material, artificial ivory, etc., because they quickly and thoroughly mix and masticate the substances under treatment and require practically no attention. The kneading troughs and blades of all machines of this type are constructed for heating by steam up to 6 atmospheres pressure. Emptying is effected by raising the hinged flap, which is in some machines counterbalanced. In view of the great resistance offered by the materials under treatment, these machines are very sturdily built, being geared on both sides. The capacity ranges from $\frac{2}{3}$ to 68 gallons.

For treating materials *in vacuo*, a balanced air-tight lid is fitted to the trough with a flexible exhaust pipe, an observation window and a special arrangement for trapping any moisture of condensation. The troughs, and, where neces-

sary, the blades also, are steam-heated, while means are provided for ensuring that no lubricant shall work its way into the charge from the bearings.

For the mixing of certain materials offering but slight resistance, such as thin doughs and pastes, the single-bladed machines find a wide use.

A feature of the two-speed machine which is used for such materials as face creams is the "coaxing" effect of the perforated blades with which it is fitted. The machine is started on the slow speed and gradually worked up to the fast speed. On this machine may be fitted a revolution recorder, which, when the predetermined number of revolutions has been made, sets a bell ringing, and warns the operator when to stop the operation.

An efficient machine for mixing such materials as shoe and rubber cements, wax crayons, pigments, putty, paint bases, ointments, stove polish, and similar materials is the kneader shown in Fig. 20B. In this machine the mixing arms travel up the sides and down the centre of the trough, overlapping in the centre. When equipped with gearing for direct motor drive, the motor is mounted upon a base under the mixing tank, making a self-contained unit. This mixer is constructed with heavy cast-iron legs and cross braces. A tilting device is fitted so that a hand wheel enables the trough to be tilted while the

machine is running. Such machines are made in capacities ranging from 7½ to 99½ gallons, the agitator speed being about 30 r.p.m.

In some kneaders the double spiral agitator, as shown in Fig. 20C, is used. Such a machine will rapidly mix doughs and pastes, such as condensed mincemeat, lithograph ink and white lead. The frame, gearing and mixing screws are naturally very strong for this type of work, and the tank is supported by trunnions at the head, resting on top of the mixer legs. The machine is geared in such a manner that the two spiral agitators revolve in opposite directions, the ensuing mixing action carrying the material from end to end, backward and forward. The capacity of the tank ranges from 55 to 246 gallons.

The type of kneader shown in Fig. 20D is adapted for dampening and wetting down ready for percolation ground leaves, bark, etc. The alcohol, or other dampening liquid, is run into the tank and sprinkled over the batch through a perforated pipe which is connected by a hose to the supply tank. The agitator used is similar to some types employed for stirring liquids, but is very much heavier in construction.

Fig. 20E is typical of the type of knives fitted to some kneading machines. These knives are usually of hand-forged steel and fitted with heavy steel spindles, being secured thereon with lock nuts. At each revolution they scoop the material

from the bottom and turn it over to the top of the mixer, while at the same time they impart a horizontal motion to the mass.

Machines of this type are made in many sizes for large or small requirements; they are of simple construction and powerfully built. The pan is constructed of steel, copper or brass, and swings between two heavy standards. The gearing which drives the knives is covered in to protect it from the entry of dirt or dust.

In some machines a two-bladed knife, such as that shown in Fig. 20F, is fitted at either end of the trough. They are quickly detachable and rotate in opposite directions in such a manner as to prevent the contents of the trough from gathering in a mass during the process of mixing. In this machine the material can be instantly ejected by drawing the catch: if thick in consistency, the hopper may be swung completely over to discharge into a vessel placed underneath. If the mass is thin the trough is slowly tilted until the liquid discharges over the lip. In either case the knives are kept going, as they assist the discharge and prevent sediment from collecting, should the materials undergoing mixture have that tendency. Such a machine has a capacity up to 16 cu. ft., the pulleys making from 75 to 170 r.p.m.

A more complicated system of knives is that shown in Fig. 20G, which has been used very

successfully for kneading molasses and meals, aeroplane dope, photographic materials, soaps, paints, oils and greases, rubber solutions, gums, pastes and sugars. In this machine the knives are at right angles to each other, to keep the whole contents of the trough in motion and also to clean the walls of the pan.

Some of these machines are fitted with a special locking device which prevents the lid from being opened while the machine is running. The outlet can be either a sliding door operated by a hand wheel through a rack and pinion, a plunger valve operated by hand wheel or lever, or a treacle tap. Such machines range from 2 to 160 gallons in capacity, and require from $\frac{3}{4}$ h.p. to 11 h.p.

Kneaders fitted with knives take various forms. In some the kneading is done by a simple single-bladed knife, bent at right angles, fitted to each end of the trough. In others a series of fin-shaped knives is fitted to two horizontal spindles, so arranged that the whole of the contents of the trough come under the action of the knives, so that the mass is kept moving.

For heavy materials of a doughy nature, such as pill masses, lozenges, soaps, plaster and putty, the kneader shown in Fig. 21A has proved popular. This consists of double spirals which first rub the mass together and then tear it apart. The machine will run with the trough tilted at any angle. The tank is of cast iron, polished inside,

while the screws are of the same material and heavily galvanised. Such machines will mix up to 6 gallons with a pulley speed of 60 r.p.m.

A machine specially designed for mixing materials containing bitumen or substances of a siliceous nature is that illustrated in Fig. 21B. In this machine the mixture, heated to drive off moisture and open the pores, is placed in a cylindrical container, mounted on axial trunnions, and equipped over half its inner surface with angularly-disposed blades. The container is rotated through gearing to agitate and cascade the contents. When uniformly mixed, about 10 per cent. of a bituminous binder, heated to a temperature above that of the aggregate, is sprayed on to the cascading material through spaced nozzles supplied by pipes through the hollow trunnion. Gas under pressure is then admitted to the container through the nozzles, to assist the penetration of the aggregate by the binder. If the composition is to be stored, a proportion of light volatile oil is added.

A machine which has been used for such purposes as tempering chocolate just before moulding, operating on a continuous basis, consists of a horizontal barrel which may be jacketed. Through this barrel runs a shaft equipped with streamline vanes, some of which impart to the material a forward movement, and others (equal in number) a backward movement. The rapid movement,

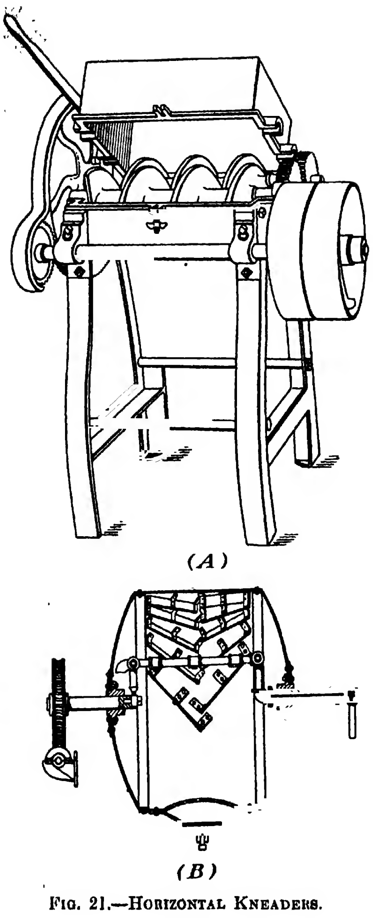


FIG. 21.—HORIZONTAL KNEADERS.

forward and backward, applies to the mass a shaking effect which is required in some processes, and the intensity of the mixture is to a large extent governed by the speed at which the machine is running. The material is fed slowly to the barrel, and all air is excluded, as air bubbles are found to hinder the kneading process, acting as buffers.

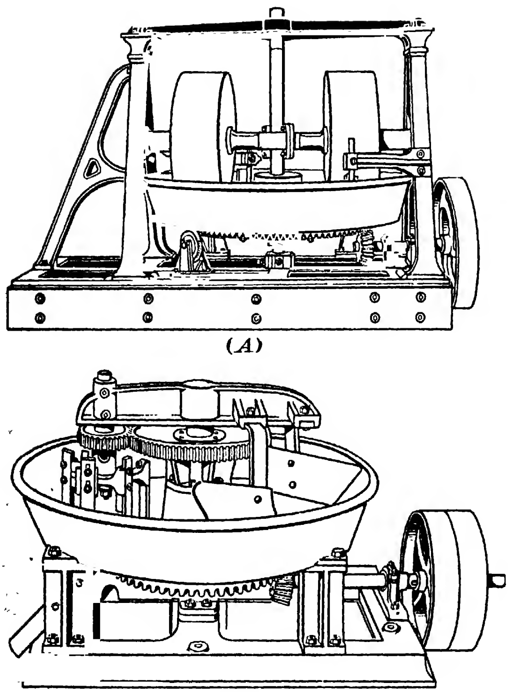
This machine has a capacity ranging from ¼ to 4 tons per 10 hours, requiring up to 8 h.p. Such a machine is used for continuously breaking down cream and fondant waste to a condition suitable for moulding in starch in one operation. It will also break hard fondant and cream to a condition suitable for the pans.

For grinding and mixing, wet or dry, such substances as clay mills of the edge runner type with revolving pans may be used. For most purposes such mills are to be preferred to mills with stationary pans in which the runners are rotated by an upright shaft, as they consume less power and there is less wear and tear on the gearing and framework. Fig. 22A shows an under-geared mill of this type in which the pan revolves, driven by belt pulley and gearing, the friction rollers being stationary. Various modifications of this standard design are in use. In some cases the pans are fitted with reduction gearing so that they can be driven from shafting running at high speeds, while in others either one or two inter-

mediate gears are fitted where a motor is geared direct to the mill.

Though pan mills with the driving gear underneath the pan and bolted direct to the foundation are preferred by many on account of the framework and centre shaft being relieved of much strain, there are some cases in which, from the location of the driving power, or due to other causes, it is more convenient to drive the mill from above. These mills may be driven by belts combined with a steam engine, or combined both with a steam engine and boiler. The range of sizes in which these mills are constructed is shown in Table III (p. 100).

A mixing pan mill where no grinding has to be done is that shown in Fig. 22B, which is used for such materials as concrete, tar macadam and substances of such-like consistency. A feature of this mill is the revolving stirrer, which consists of six steel beaters fastened to a cast-iron head fixed on a vertical spindle, connected by gearing to a wheel on the centre shaft. The pan may be made to revolve or it may be stationary with the stirrer and scrapers turning round it; in the latter case the central wheel is bolted to the dome of the pan or to the crosshead, and is stationary. In both cases the shaft carrying the beaters is made to revolve so that they turn on their own axis as well as running round the pan. Adjustable scrapers are fitted to throw the material from the outside



(*A*)

(*B*)

FIG. 22.—KNEADING PAN MILLS.

TABLE II.—Capacity of Universal Kneading Machines.

Size.	Cubic Capacity.	Capacity in Gallons.	Capacity in Litres.	Size.	Cubic Capacity.	Capacity in Gallons.	Capacity in Litres.
3	65 cubic in.	1½ pints.	0·9	15½	18·3 cubic ft.	110	500
4	0·08 cubic ft.	½ gall.	2·5	16	22·0 ,,	132	600
5	0·16 ,,	1 ,,	5	17	29·3 ,,	176	800
6	0·33 ,,	2 galls.	9	18	37·0 ,,	220	1,000
8	0·66 ,,	4 ,,	19	20	55·0 ,,	330	1,500
11	1·33 ,,	8 ,,	38	21	73·0 ,,	440	2,000
12	3·00 ,,	18 ,,	80	22	83·0 ,,	495	2,250
13	3·7 ,,	22 ,,	100	23	111·0 ,,	660	3,000
13½	5·5 ,,	33 ,,	150	26	183·0 ,,	1,100	5,000
14	7·3 ,,	66 ,,	200	30	370·0 ,,	2,200	10,000
14½	11·0 ,,	66 ,,	300	31	445·0 ,,	2,650	12,000
15	14·6 ,,	88 ,,	400				

Owing to wide variation in specific gravity of materials treated, capacity can only be expressed in liquid measure and cubic dimension.

TABLE III.

Diameter of pan at top, outside	4′ 0″	4′ 6″	5′ 0″	5′ 6″	6′ 0″	6′ 6″	7′ 0″	7′ 6″	8′ 0″	9′ 0″
Revolutions of pan per minute	28	28	24	24	22	22	20	20	18	18
RUNNERS: Diameter . . in.	24	24	30	32	36	36	39	39	42	42
RUNNERS: Width on face . in.	9	10	11	12	13	14	15	16	17	18
RUNNERS: Approximate weight of each . cwt.	6	8	11	13	16	18	21	24	27	30
Actual brake horse-power required to drive these mills	3	4	6	7	9	10	12	14	16	20

TABLE IV.

Diameter of pan at top, outside	4′ 0″	4′ 6″	5′ 0″	5′ 6″	6′ 0″	6′ 6″	7′ 0″	7′ 6″	8′ 0″	9′ 0″
Revolutions of vertical shaft per minute	24	22	21	20	19	18	16	15	14	13
Actual brake horse-power required to drive these mills	3	4	6	7	9	10	12	14	16	20
DRIVING PULLEY: Diameter . in.	18	18	24	24	30	30	36	36	42	42
DRIVING PULLEY: Width on face . in.	4½	4½	5	5	6	6	6	6	6	6
DRIVING PULLEY: Revolutions per min.	102	94	89	85	80	80	80	75	75	65

and centre of the pan into the path of the beaters. In mills with the stationary pan a large hinged door is fitted in the bottom of the pan, and is operated by a lever. In mills with the revolving pan the material has to be removed by means of a shovel. Typical sizes of these pans are shown in Table IV.

CHAPTER IV

EMULSIFYING MACHINERY

VARIOUS types of machines have been designed for the emulsification of liquids, and for beating and rubbing creams, ointments, extracts and similar substances. Several of the units described in Chapter II can be used for this purpose. A simple machine of this type is that shown in Fig. 23A, which is used for making emulsions, mixing casein glue and other substances in small quantities. The tank of this machine is made of iron, and can be fastened down to a bench or table. The beater blades, which are worked on the ordinary whisk principle, are large and geared in such a manner that a high speed can be obtained with little manual effort. Emulsifiers of this type are, however, very small, and are rarely used for capacities greater than 2 gallons.

Beaters for emulsifying are of various shapes, some of which are shown in Fig. 23B. The wing beaters can be driven from tight and loose pulleys, placed at the end of the horizontal machine, or the entire emulsifier can be mounted on a cast-iron base and connected to a motor by gear reduction. The tanks for such emulsifiers are often made of galvanised sheet iron with a cooling jacket, mounted on a cast-iron frame and equipped for easy dumping.

In some cases a double-motion machine is used, the beaters consisting of rods mounted as shown

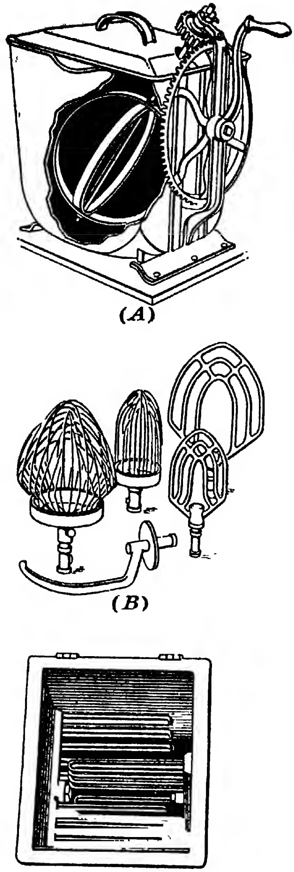


FIG. 23.—EMULSIFIERS

in Fig. 23c, driven from each end and running in opposite directions.

A comparatively new machine for effecting the disintegration and emulsification of liquids and the intensive mixing of solids and liquids, and the blending of difficult miscible constituents in various chemical preparations is the "Premier" mill, shown in Fig. 24. As will be seen from the diagram,

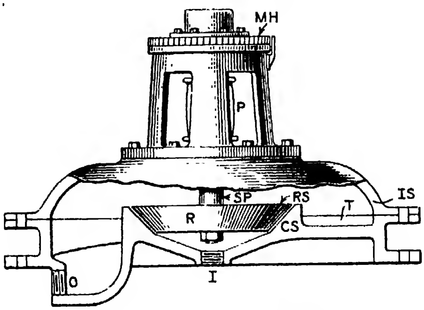


FIG. 24.—THE PREMIER MILL.

this mill consists of an outer casing which surrounds the rotor, R. This rotor consists of a smooth steel cone made to extremely fine limits and fixed to the spindle, SP, which is mounted in special bearings. The cone operates in close relation to a fixed surface, CS, which forms part of the casing, the arrangement being similar to the action of the clutch in an automobile engine, except that the two surfaces do not touch.

The working surface of the rotor RS is arranged

so that there is a very fine clearance between it and the surface of the casing, CS. The rotor turns at a speed which varies from 1000 to 5000 r.p.m., and is driven by the pulley, P, mounted on the spindle, SP. The bearings which control this spindle are mounted in the head, MH, and in the top casing of the machine immediately below the pulley. The micrometer head enables the clearance between the rotor and the cone to be adjusted to the desired degree. It will be seen then that the action of this mill is to disintegrate and emulsify between the rotor and the casing.

The rotor is never adjusted so that it actually touches the casing, but it can be so regulated that the actual clearance can be from 3/1000 in. to 3/100 in., according to the nature of the work to be done. It must be realised, of course, that when the mill is being used on hot materials, the expansion of the metal parts must be taken into consideration, and the clearance should not be adjusted until the machine has become thoroughly heated up.

In operation, the material to be dealt with is fed through the inlet, I, at a suitable rate, either by pump or gravity. Very little head is required when feeding by gravity because the rotor acts as a centrifugal pump and assists the feed by drawing in the material between the working surfaces. If necessary, this mill may be jacketed for either heating or cooling.

The drive is usually by belt, either direct from the motor pulley or through a countershaft; for the larger machines the use of the countershaft is recommended. In some cases the mills are driven by an overhead motor. Other drives are by petrol engine or direct-drive from a steam turbine.

The angle of the rotor is usually set at 45 deg., but for special purposes this angle is altered.

Examples of the power required for producing certain typical products with this mill are given below:

Taking the case of the standard 15 in. mill, which is driven by a 25 h.p. motor, and running at a speed of 3500 r.p.m., it is found that the actual power absorbed by the material passing in between the working surfaces is somewhere in the neighbourhood of 4 to 5 b.h.p., when 1000 gallons per hour are passing through the unit. This applies for liquids of the viscosity of water or thereabouts. The power absorbed by the motor and the installation running light, naturally depend upon the type of motor, countershaft, etc., and will vary between 5 h.p. and 10 h.p.

Another typical example is that of enamel. This material, as is well known, is very viscous even when prepared ready for the brush. With an output of 25 to 35 gallons per hour, about the same power is used as in the previous example,

the exact figure depending upon the viscosity of the material.

As a rule a 25 h.p. motor is recommended where the running load is somewhere between 12 and 15. In all cases the output and power required depend upon the viscosity of the medium, but with a total h.p. per mill of from 12 to 15, the outputs are roughly graded as follows 9 :

1. Emulsions, such as creosote, petrol, and water, 1000 gallons per hour.

2. Emulsions of a viscosity equal to that of linseed oil, 500 to 600 gallons per hour.

3. Powdery substances, suspended in water, suspension containing 20 to 40 per cent., 400 to 500 gallons per hour.

4. Paints and enamels, 30 to 80 gallons per hour, according to the viscosity.

All these particulars apply to the standard 15 in. mill. In the case of non-viscous emulsions a 15 h.p. motor is sufficient for the installation.

Plauson's colloid mill which is the mechanical agent in Plauson's system of mixing, disintegration, and emulsification, is shown in Fig. 25. This differs from most other disintegrating agents in that it substitutes for friction and pressure an exceptionally high velocity, communicated to semi-liquid contents by means of a number of beaters passing between stationary anvils, with

appreciable clearance, and having a peripheral speed of 3000 metres per minute and upwards, the total number of impacts per minute being in the neighbourhood of 168,000

The chemical agents, which are essential to

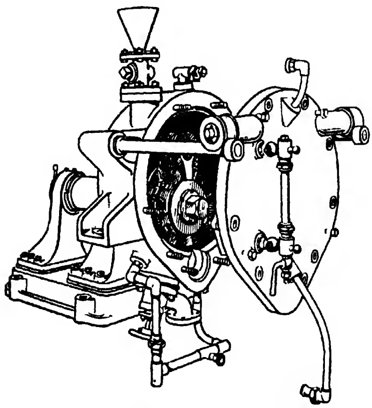


FIG. 25.—PLAUSON COLLOID MILL.

colloidal dispersions and the stabilisation of emulsions, are known as dispersators and are determined for each substance by trial and experiment. These are mostly common and inexpensive substances such as gums, glues, gelatines, and soap, usually innocuous as a constituent of the resulting product, and seldom used in quantities exceeding 1 per cent.

The colloid mill itself consists of a stout circular body made of cast iron specially treated to resist corrosion. The body is jacketed in the casting, the jacket being used either for cooling by water or heating by steam. A filling branch is provided with a removable baffle tube, funnel, and inlet valve. There is also a charge hole for admitting dry solids. At the bottom of the mill is an outlet branch fitted with a plug valve.

In the lower part of the mill cavity is fitted a rotating shaft carrying a number of beaters or hammers arranged at eight points around the circumference. These beaters consist of steel blades, securely keyed on the shaft with distance pieces between them of rather greater thickness than the blades. Above and below the axis of the revolving shaft carrying the beaters there are fixed in the body casing of the mill corresponding sets of fixed blades at suitable distances apart, in order that the revolving blades may pass clear between them, the clearance being about 1 mm.

Curved and perforated baffle plates are placed concentrically with the axis of the beater shaft just beyond the beater track and enclosing the greater part of it. These plates do not, however, extend to the lower part of the track, the object being to leave ample space for free contact with the material under treatment.

The front cover of the mill is so designed that it may be removed quickly for examination of the interior of the mill and to allow of cleansing when the materials treated are changed. The weight of this cover is taken on runners supported by projecting steel spindles secured in the mill body, so that the cover can be drawn back easily and replaced without having to be lifted. The end cover is also jacketed.

The Plauson colloid mill has already found useful application in several industries. Technically true colloidal dispersions in water and other liquids have been made of sulphur, indigo, china clay, resin, alumina, rubber, graphite, barytes, thionol yellow, lithopone, naphthalene, cellulose, and caledon yellow. It is also claimed that the necessary dispersing and stabilising agents have been found and highly stable emulsions have been produced in water of such substances as fats, waxes, mineral oils, animal and vegetable oils, creosote, bitumen, pitch, carbon tetrachloride, oleic acid, carbon bisulphide, cresylic acid, and tar oils.

Neither the size of the mill nor its velocity affords any indication of its output capacity, nor can factory working conditions be so simulated in a laboratory as to enable the deduction of more than approximate data, but most of the emulsions mentioned are effected by a single flow-through operation at a speed indicating a potential output

of 2 tons and upwards per hour. Oxide of iron, barytes, carbon blacks, bones, clay, oxide of zinc, and mica have been reduced to colloidal fineness in from 1 to 15 minutes, and to intermediate grades of fineness in proportionately less time. An output of 220 lb. per hour of colloidal sulphur effected with 10 h.p. under laboratory conditions might be increased by nearly 100 per cent. by suitable mechanical feeding.

With these and substances having similar physical characteristics it is possible to secure a continuous flow-through operation by a judicious arrangement of feeding devices. In some cases it should be advantageous to use two or more mills in series; in others to separate the tails from the ground material and return the former for further treatment—*i.e.*, to employ the mill in a closed circuit system.

Laboratory observations indicate about 8 h.p. for emulsions, 10 h.p. to 15 h.p. for paint pigments, blacks, dyes, etc., in oil or water, 20 h.p. for colloidising barytes, and that power requirements are varied within wide limits by the rate and quantity of feed, fluidity, viscosity, and other physical conditions.

While there are several technical definitions, a colloidal dispersion may for industrial purposes be defined as something between a temporary suspension of a solid in a liquid, such as mud, and a

permanent molecular solution such as that of sugar in water, and exhibiting the Brownian movement. A solid may be of colloidal fineness without necessarily being dispersed in a liquid medium. So far as it is possible to express it numerically, colloidal fineness implies particles from 0·1 μ to 0·01 μ or less, *i.e.*, 1/250,000 to 1/2,500,000 of 1 in. in diameter. Below is given a table which compares particles of colloidal size with those of dimensions measurable by screens.

Comparison of Dimensions.

1 mm. (millimetre) = 0·03937 in. = about $\frac{1}{25}$ inch.
1 μ (micron) = 0·001 mm = 0·00003937 in. = about 1/25,000 in.
Diameter of Colloids: 0·1 μ = 0·0001 mm = 0·000003937 in. = about 1/250,000 in.
0·01 μ = 0·00001 mm. = 0·0000003937 in. = about 1/2,500,000 in.

Comparison of Wire Meshes.

No. of meshes per linear inch.	British Standard gauge wire No.	Internal diameter of mesh pores.
100	40	132 μ = 0·0052 in. = 1/192 in.
200	45	56 μ = 0·0022 in. = 1/455 in.
300	50	38 μ = 0·0015 in. = 1/666 in.
* 125,000		= 0·1 μ = 0·0000039 in. = 1/250,000 in.

* If it were possible to construct a wire sieve having 125,000 meshes to the linear inch (wire having a cross-section of 1/250,000 in.) particles below 0·1 μ diameter would pass through, but those of and above this diameter would be retained. The holes of such a mesh would be 144,400 times smaller than those in the 300 mesh. 0·1 μ is the size of a large colloidal particle, and even smaller particles, as will be seen from the tables, are obtained in the Plauson colloid mill.

On p. 114 is given a table of the results achieved with various substances in the Plauson mill, the figures showing the size of the particles both before and after treatment in the mill.

Table V.—Treatment of Various Substances in Plauson Colloid Mill.

Sizes of Particles before and after Treatment.

	Above 1000 μ %	1000–400μ. %	400–45 μ %	45–4 8μ. %	4·8–1 μ. %	1·0–0·01 μ. %
Red oxide of iron :						
Before .	0·05	3·3	56·7	34·6	3·4	1·5
After .	—	—	—	10·9	13·0	76·1
Lithopone :						
Before .	0·4	3·0	17·0	68·0	11·5	—
After .	—	—	0·2	1·4	11·8	86·5
Zinc white :						
Before .	—	—	1·75	56·5	41·7	—
After .	—	—	—	1·9	98·0	—
Bauxite :						
Before .	—	3·8	42·2	54·0	—	—
After .	—	—	—	14·9	79·8	6·2
Burnt ochre :						
Before .	3·8	8·2	34·4	52·0	1·6	—
After .	—	—	5·2	33·3	24·7	36·6
Amaranth :						
Before .	0·45	1·5	25·0	52·7	18·3	2·4
After .	—	—	—	0·15	0·30	99·5
Kessler brown :						
Before .	—	—	10·4	33·1	56·5	—
After .	—	—	—	0·2	20·3	79·5
Green earth :						
Before .	—	—	2·6	18·9	76·7	1·6
After .	—	—	—	—	6·6	93·4
Phosphates :						
Before .	—	2·5	51·1	45·0	1·1	—
After .	—	—	—	18·2	75·0	6·8
Mica :						
Before .	69·2	0·9	17·5	12·4	—	—
After .	—	—	—	6·0	81·0	12·9
Carbon black :						
Before .	—	6·7	17·2	43·2	20·2	12·7
After .	—	—	—	—	3·1	96·0

CHAPTER V

VESSELS FOR AGITATING, STIRRING AND KNEADING

THE vessels in which agitating and kneading operations are carried out are of various shapes and materials and may be either plain or jacketed. Some such vessels consist of mild steel bodies with welded joints, flanges and feet, the vessel itself being cylindrical with the bottom curved to facilitate discharge through a bottom valve. Other bodies consist of plain hemispherical copper kettles. For horizontal kneading or agitating the container often consists of a single steel plate bent to shape and strongly framed with angle irons securely bolted to end frames, which are macnined smooth and bright on the inside. The interior of the vessel is treated to give a dull polished surface. In some cases containers are galvanised.

Fig. 26A shows a rotary batch mixer in which the drum is formed in halves which are separated for discharging. In this vessel the sliding half mounted on a sleeve is equipped with a central neck through which extends a sleeve on the boss on the other half fixed to the shaft. By these means the shaft is protected from contact with the contents of the vessel.

In the chemical industry, however, the majority of the vessels used for agitating and kneading are jacketed either for cooling by water or heating by steam, and Fig. 27 shows some typical agitating and kneading vessels so jacketed.

Fig. 26B shows a typical seamless one-piece kettle much in favour to-day for various mixing operations. This kettle is constructed by the use of three moulds; the upper half of the mould which forms the inside of the kettle, the core which forms the jacket, holes in this core forming the reinforcing connections or staybolts between the two walls, and the lower half of the mould which forms the outside of the kettle. These three parts are then assembled and the entire kettle is formed by one pour. The metal used for these kettles is a high silicon, low manganese and low phosphorus iron of close grain, high ductility, and a tensile strength between 35,000 and 40,000 lb.

Fig. 26C shows another type of jacketed agitating kettle and cover.

Fig. 26D is a kettle in which the usual heating jacket is replaced by coils of seamless steel tubing cast into the cast-iron body of the apparatus in such a way as to form a homogeneous mass with the iron.

Where live steam under boiler pressure is not easily available a self-contained kettle and steam generating plant is used. The independent coil heater is operated by gas, and a pressure of from 60 lb. to 80 lb. on the jacket is obtainable within 15 minutes.

In some cases, for instance, when dealing with corrosive liquids, lined vessels are necessary for carrying out agitating or kneading operations.

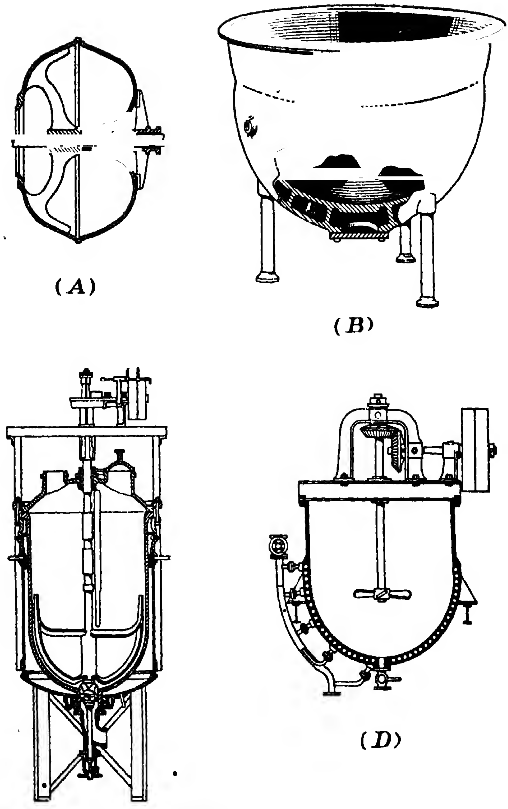


FIG. 26.—VESSELS FOR AGITATING AND KNEADING.

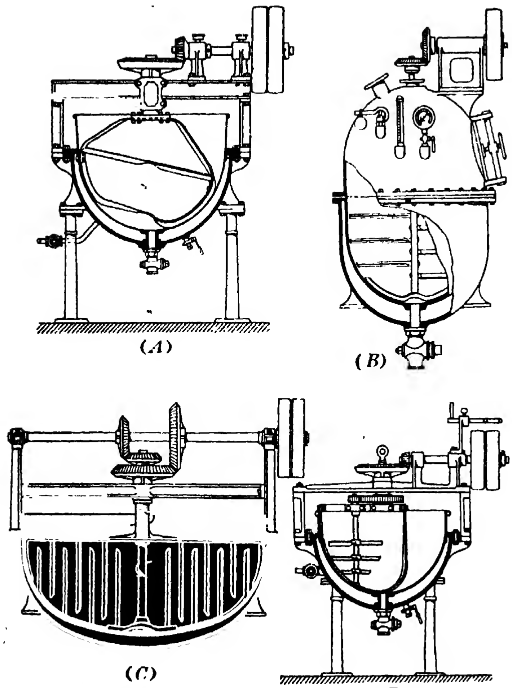


FIG. 27.—JACKETED VESSELS FOR AGITATING AND KNEADING.

For such purposes glass enamel-lined vessels are used with success, the kettles being either plain or jacketed. A typical agitator kettle of this type is made of all-welded $\frac{5}{16}$ in. open hearth plate steel, trunnions are welded to the jacket, the steam inlet being through the trunnion.

Closed type jacketed mixers constructed on the same principle are in common use under vacuum or pressure for heating a wide variety of solutions containing strong organic and inorganic acids. The agitator is also glass-coated, and the inner tank has an enamelled outlet through the welded connection in the jacket. The manhole cover is enamelled. Such vessels are commonly used up to 550 gallons capacity.

Enamel-lined emulsifiers equipped with cast-bronze double-motion, inter-meshing agitators are used for such products as cod-liver oil, tonic emulsions, face creams and for other preparations where a beating, slapping effect is desired.

Agitators made of steel and glass-enamelled are constructed for use in vessels of the above type.

Vessels for agitating are also constructed of chemical stoneware, which are made of clay bodies with a vitreous acid-proof glaze. Agitating kettles of this material are usually made up to about 170 gallons capacity. The cover is equipped with a gas outlet and inlet, as shown in Fig. 28, and a stuffing box for the stirrer. The shaft, in the larger sizes of stirrers, is made with a hollow

centre which permits the cementing in of a steel shaft which then becomes the driving shaft proper, the stoneware shaft acting as protection for the steel shaft. Melted sulphur or other cementing

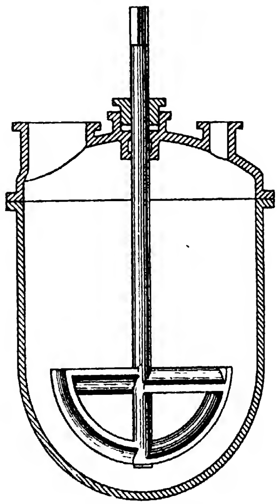


FIG. 28.—ACID-PROOF 50-GALLON NITRATING KETTLE WITH STIRRER.

compounds are used for cementing in the shaft. In the smaller sizes, the stoneware shaft is made with a square head as shown for attachment to the driving mechanism. In this equipment the principal strain on a stoneware shaft is in starting and stopping, so that when the agitator is being

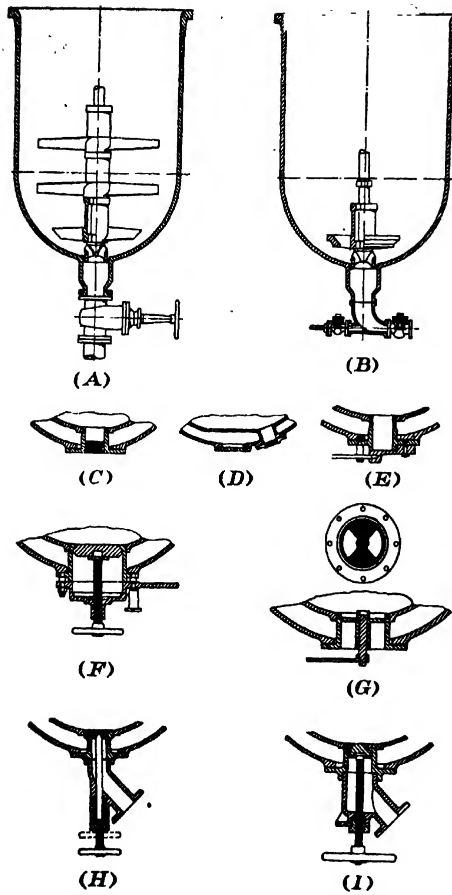


FIG. 29.—VARIOUS STYLES OF OUTLETS.

used the mechanism should be started up and stopped gradually.

Various types of outlets for agitating and kneading vessels are shown in Fig. 29. Fig. 29A is a standard type and is controlled by a gate valve. Where solids are used in such quantities that the discharge line and outlet are subject to clogging, the arrangement shown in Fig. 29B is used, consisting of a blow-off steam line controlled by plug cocks. In the case of Fig. 29C, the end of the sleeve is screwed into the inner shell of the kettle; the machined joint between the bottom of the kettle and the top of the outlet flange is absolutely tight at 150 lb. hydrostatic pressure without packing. The outlet, Fig. 29D, does away with the threaded joint between the inside of the kettle and the jacket, thus making a seamless unit. This outlet cannot be placed exactly in the centre of the kettle bottom, the distance from the centre of the kettle to the edge of the outlet ranging from 3 in. to 10 in., depending upon the size of the kettle, with the bottom of the kettle flattened so that the contents will drain. Fig. 29E is an outlet with a boss on the kettle bottom to which is fitted a gate; this is not suitable for handling thin liquids. When the outlet, Fig. 29F, is closed the plug comes flush with the inside of the kettle bottom. To open, the plug is screwed down into the pocket, whereupon the entire valve is swung to the side, like a gate, leaving a clear, unobstructed

opening. This is designed chiefly for materials containing granular or crystalline substances. The butterfly valve type is shown in Fig. 29G, flush with the inside of the kettle. This is used for handling liquids in the bridge type agitators, as the vertical shaft of the agitator, bearing on the step in the valve, is necessary to maintain a tight joint between the valve and the seat. The types in Figs. 29H and 29I, closing flush with the inside of the kettle bottom, do away with the pocket of unmixed material in the outlet, such as occurs in Figs. 29C and 29E. The choice between these two depends entirely upon the nature of the material being agitated in the kettle.

CHAPTER VI

MIXING, GRINDING AND DILUTING PAINT IN PEBBLE MILLS

In the Abbé process of paint making (English Patent No. 176,794), the mixing, grinding, and diluting of the paint paste are all done in one air-tight container from which it is not removed before it is entirely finished. The apparatus consists of a container, usually cylindrical, which is about half filled with freely moving grinding bodies, preferably flint pebbles, by the action of which the material is ground. On the inside of the cylinder is usually secured a heavy lining of burr stone of good wearing quality. The cylinders are provided with a manhole which, in all machines over 30 in. in diameter, is of sufficient size to permit the entry of a man if desired. In the manhole cover, or in one of the cylinder ends, is provided a cylindrical brass plug extending through the lining. The plug is quickly removable and its object is to permit entrance of air to the mill during the discharge of the ground product, and also to provide an easy means of withdrawing samples of the grinding as this progresses. On the body of the mill, opposite the manhole, is placed a cast-iron block to balance the excess weight of the manhole fittings. In this balance block and extending inward near the face of the burr stone lining is placed a valve chamber in which is inserted a bronze gate in which the openings are closed with a

butterfly wing piece, also of bronze, with a stem extending to the outside of the mill. By means of a handle on the stem the wing-piece is moved to open or close the grate surface for the passage of the completed product, while the pebbles are retained. The valve chamber forms a funnel with a slope towards the outlet which is fitted with a short piece of pipe to facilitate attachment to any required fitting during discharge.

Mills having cylinders up to 3 ft. 9 in. in diameter are usually revolved by means of tight and loose pulleys on one of the cylinder trunnions, while mills larger than this are operated by machine-cut gearing.

The wearing parts in these mills are the lining and the pebbles. Formerly porcelain was used as a lining in pebble mills, and still is used in mills of 18 in. diameter and smaller, but burr stone has been substituted in the larger sizes. Grinding materials in water subjects the lining to greater wear than grinding in oil, but this type of lining has so far proved to be more satisfactory than any other. The pebbles used are of amorphous structure with conchoidal fracture.

In considering the nature of the action in these mills, assume the cylinder to be half filled with pebbles and the material under treatment. The revolution of the cylinder will carry the load upward until it reaches a line where gravity overcomes the friction between the pebbles. The

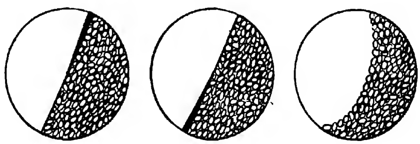
inclination of this line, which may be called the "drop" line, will vary according to the size and speed of the mill and the viscosity of the material. The faster the cylinder revolves the higher up will the load be carried before it tumbles, until a speed is reached at which centrifugal pressure will prevent movement of the load, and will entirely nullify the action of the mill. It is possible to regulate the speed so that the upper part of the load will slide gently down the incline formed by the underlying pebbles, will make a quick and jumpy slide or have a long drop. The strength of the blows or contacts between the pebbles therefore depends on the speed of the mill as well as on the size of the pebbles used. The larger the pebbles the stronger but less numerous will be the contacts; for this reason the smallest pebbles that will produce contacts of sufficient strength to perform the work are selected.

A pebble mill cylinder may be considered as an elevator carrying the material to the top of an incline down which it will tumble with more or less speed according to the slope.

In Fig. 30A is indicated in black a wedge-shaped block of material ready to slide down, and in Fig. 30B is shown the same wedge after falling. It is to be understood, however, that while these figures are theoretically correct as basis for calculations, the actual outline of thick or dry material in the revolving cylinder will be about as indicated in Fig. 30C, for the reason that centrifugal force

will be stronger at the circumference than near the centre, and because of the rebound and deflection at the bottom.

In dropping down over the mass under them, the pebbles may be said to make one contact with each projecting underlying pebble, and also an equal number of contacts sidewise. Secondary movements in underlying pebbles need not be considered, as their effect is comparatively small and does not affect the theoretical calculation. The distance



(A) (B) (C)

FIG. 30.—PAINT MIXING, GRINDING AND DILUTING IN PEBBLE MILLS.

each and every pebble will drop, if all are considered together, must be about two-thirds of the diameter of the cylinder. This means that the length of working surfaces is about two-thirds of the mill diameter, but the average vertical drop is only equal to the sine of the sliding angle in a triangle having a radius of this length. The number of times a pebble will drop during each revolution of the cylinder cannot be estimated, but should be about 1·6 for each one revolution of the mill.

When a mixture is first tried in this type of mill,

a little experimenting is necessary to determine what proportion of vehicle will give the best results when mixed with a definite quantity of pigment. There should be no guesswork as to the mixture decided upon, because the exact density suitable for the material may depend on a very small change in the proportions used. When once a satisfactory run has been obtained, all subsequent charges of equal mixture will be finished to exactly the same condition in equal time without further adjustment or test.

The amount of the pigment required to make a maximum charge in the mill, or less, has to be calculated and also the amount of vehicle to be added so as to make the desired finished paint. By experience, or a few mortar tests, will be ascertained what proportion of the total vehicle to be used will be necessary to make a soft or slowly flowing liquid paste when thoroughly worked with the entire batch of pigment. Only this part of the total vehicle is dumped into the mill together with all the pigment. The manhole cover is then put in place and the cylinder started. When the mill has been revolved a certain length of time it will have obtained a fineness exactly corresponding to the time used in operation. For some minutes after starting the mixture will be very thick and the load in the cylinder is carried higher than usual, and therefore requires more driving power than is necessary during the rest of the run.

As the operation progresses samples are obtained by stopping the mill, withdrawing the air-vent plug and inserting a narrow and bent strip of tin through the bore. If necessary, small amounts of vehicle may also be added to the batch in the mills by the use of a funnel passed through the same vent; but the funnel must be made with an air vent for the displaced air.

No attention is required for the mill while revolving, and there is no damage to the paint by reason of the fact that little heat is generated.

After the expiration of the time required to finish a charge the mill may either be discharged or the material may be diluted in the mill to finished paint. In the latter case, the cylinder is stopped with the discharge pipe on top and the thinner is poured in. A run of from five to seven minutes will then make a thorough mixture ready to discharge.

When the pigment is very bulky, as in the case of lithopone and lampblack, the cylinder may not have sufficient free space to hold all required for the maximum charge of finished paint. In such cases all the pigment the cylinder will hold may be filled in together with the vehicle required for a full charge of paste, the mill then being run slowly for a few minutes so as to wet down the pigment and condense the charge. The rest of the pigment may then be inserted. In many cases it will be preferred to run the mill with reduced charges so as

to avoid over-charging. The time needed for finishing the smaller charge is somewhat less than that for the full charge. In mixtures of pigments of which part only is bulky material the reduction in charging capacity will, of course, be in proportion to the bulk of the total mixture.

Other than the cases stated above, the weight of the pigment does not matter, and the mill will work as well on white lead mixtures as on zinc and other compounds.

When cleaning the mill from one colour to another, the cylinder is well drained, a small charge of thinner or petrol is poured in, and the mill run for a few minutes and then discharged.

The time required for finishing a batch of paint is determined by several factors, of which the principal are :

1. Quality of raw material used. Most pigments in general use are ground or otherwise prepared to so fine a condition as to require very little further grinding of the particles, and the work of the mill is principally in separating aggregates of the particles into units, to envelop these with a film of vehicle and to make a uniform mixture of the entire batch. Where poorly prepared minerals or strongly cemented precipitates must be ground to fineness, it is evident that longer runs will be necessary—for instance in the case of bone black and graphite.

Small amounts of coarse or otherwise difficult

material in a batch of finely ground pigments will add materially to the time required for preparing the mixture, and the entire operation will take almost as long as if the entire charge consisted of coarse material. For this reason it is often a saving to finish the coarse material alone by grinding it in a separate charge, and then to mix this in the proper proportion with the finished balance of the paint. The final mixing should then take only a few minutes in the pebble mill.

2. Exact quality of product required. Every manufacturer has his own standard for his product. For some a rough mixture that can be made in the simplest mixer and grinder is all that is necessary, while others demand microscopic perfection in their paint. The time of batches will be in accordance with such requirements.

3. Diameter of mill. The difference in the time required for batches in mills of different sizes has already been dealt with; a large mill is quicker in operation than a smaller one.

4. Density of the grinding paste. Some paste can properly be made considerably thicker than others, mainly depending upon the nature of the vehicle used.

5. Influence of penetration by the vehicle. Minerals will grind faster in water than when dry, while a thick varnish will retard the grinding. A thin oil may be loaded with more pigment than a heavy, sticky one.

6. Size of pebbles used. The fundamental rule is that the greater the number of contacts or blows that is made in a certain time the greater will be the number of particles effectively dealt with. For this reason the smaller the pebbles that can be effectively used for this work the better will be the resulting grinding and incorporating, but the resistance of the material under treatment must be considered so that the combined weight and speed of the pebbles will be sufficient to produce effective contacts. A heavy paste necessarily requires larger pebbles than an easy-flowing one.

From the results already achieved in this mill it has been possible to compile the time required for batches in medium-sized mills on various types of paint. The figures given below are for the actual grinding, and do not include any case where rough mixing only would be sufficient.

Roof paint	1 hr.
Ship bottom, anti-rust, etc.	2 to 3 hrs.
House paints, lead and zinc mixtures	2 to 3 hrs.
Interior white	2 to 4 hrs.
White gloss enamel (zinc oxide)	2½ hrs.
,, ,, ,, (zinc and mineral)	3 to 5 hrs.
Flat white (of many mixtures)	3 to 12 hrs.
White lead and zinc enamel	4 hrs.
Coloured enamels (according to pigments)	5 to 8 hrs.
Celluloid	5 to 10 hrs.
Shellac varnish colours	3 to 5 hrs.
Metal decorating coatings	2 to 4 hrs.
News ink	4 to 6 hrs.
Black in castor oil (leather dope)	6 hrs.
Pulp black	3½ to 4 hrs.
Coach black	20 to 40 hrs.
Bone black in lacquer	32 to 50 hrs.

TABLE VI.—Pebble Mills for Paint Mixing, Grinding and Diluting.

Diameter of Cylinder	Length of Cylinder.	Maximum Capacity of Paint Charge in Gallons.	Floor Space Required.	Height of Mill.	Size of Pulleys.	Gear Wheel and Pinion—Number of Teeth	Amount of Pebbles Furnished.	Horse Power used During Run Averaged.	Horse Power used to Start Mill.	Speed of Cylinder, R. P. M.
							Lb.			
15″	19″	4·5	3′ 2″ × 2′ 3″	3′ 4″	15 × 2″	—	60	¼	½	57
18″	27″	10·5	3′ 9″ × 2′ 6″	3′ 6″	18 × 2″	—	125	½	¾	53
2′ 6″	22¾″	24	4′ 9″ × 3′ 9″	4′ 9″	24 × 4″	—	330	¾	1¼	38
2′ 6″	2′ 9½″	40	5′ 6″ × 3′ 9″	4′ 9″	24 × 4″	—	440	1	1½	38
3′	3′ 6″	67	6′ 9″ × 4′ 3″	6′	36 × 6″	—	770	1¾	2½	33
3′	4′	78	7′ 3″ × 4′ 3″	6′	36 × 6″	—	880	2	3	33
3′ 9″	3′ 6″	100	7′ 6″ × 6′	6′ 4″	45 × 6″	—	1,160	2½	4	27
4′ 6″	3′ 6″	170	9′ × 6′	7′	24 × 6″	102—12	2,100	3	5	23
4′ 6″	5′	260	10′ 6″ × 6′ 6″	7′	24 × 6″	102—12	2,800	4	7	23
5′	4′	250	11′ × 7′	8′	28 × 8″	105—14	2,750	5	9	20
5′	6′	410	14′ × 7′	8′	28 × 10″	105—14	4,070	7	13	20
6′	5′	480	14′ × 8′	9′ 6″	30 × 10″	90—16	5,000	9	16	16
6′	8′	840	17′ 6″ × 8′	9′ 6″	36 × 12″	90—16	8,300	15	22	16

The time required for treatment in the mill as given in the above list indicates that where no great force is needed to break up the particles or aggregations of articles, as is the case with the usual zinc oxide enamels and flats, the work is quickly done, but more time is required where imperfectly ground materials or hard precipitates have to be reduced to a proper fineness in the mill.

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